Proceedings of the Linear Accelerator Conference 1990, Albuquerque, New Mexico, USA

ERROR AND TOLERANCE ESTIMATES FOR THE SSC CCL*

T.S. Bhatia, R.W. Garnett, and G.H. Neuschaefer,
Los Alamos National Laboratory
and
K. R. Crandall
AccSys Technology Inc., 1177 Quarry Lane, Pleasanton, CA 94566

Abstract

We have used a new code, CCLTRACE, to estimate error and tolerance limits for two possible examples of a 1284-MHz, 70- to 600-MeV coupled-cavity linac (CCL) for the SSC linac. By calculating the dynamics of the beam center as well as the beam ellipsoid, CCLTRACE can efficiently perform error studies using Monte Carlo techniques.

The Code CCLTRACE

After a CCL is designed, its performance is usually checked by a multiparticle simulation code, such as CCLDYN, which can estimate beam loss and emittance growth and display beam profiles and phase-space projections at points along the length of the CCL. The code CCLTRACE replaces the multiparticle dynamics of CCLDYN with the beam ellipsoid dynamics of TRACE 3-D.[1] CCLTRACE is related to CCLDYN in the same way that PARTRACE[2] is related to PARMILA.

Ken Crandall developed CCLTRACE to estimate the effects that are due to the presence of various error conditions, singly or in combinations, for CCLs. When tolerance limits on one or more types of errors in alignment or field adjustment (random over a uniform distribution of ± specified limit) are specified, CCLTRACE can calculate probability distribution functions for various effects on the beam. For example, for a specified set of tolerances, the user can determine the probability that the beam center will not be displaced from the axis by more than a certain distance or that the outer edge of the beam will not go beyond a certain fraction of the available bore. Using information generated by CCLTRACE, the CCL designer can set reasonable tolerances on the various types of unavoidable errors. Alternatively, CCLTRACE can help establish the need for corrective action along the structure in order to compensate for the effects of errors within specified tolerance limits.

To glenerate the probability distributions, the code runs a large number of "traces" for a specified set of tolerance limits. At each element, random values within the tolerance limits are chosen for the errors. Maximum values for the beam parameters and emittances are saved for each trace. At the end of a run, these values are sorted and a probability distribution is obtained.

CCLTRACE can be used for error estimates for CCLs with either singlet or doublet focusing lattices. The types of error conditions that can be handled by CCLTRACE, singly or in combinations, are

a. quadrupole displacements
b. quadrupole rotations (roll)
c. quadrupole tilts (pitch and yaw)
d. quadrupole gradient errors
e. doublet displacements
f. doublet tilts
g. doublet rotations
h. doublet gradient errors
i. tank displacement
j. accelerating field amplitude errors
k. accelerating field phase errors
l. initial beam mismatch errors

Error and Tolerance Estimates for SSC CCL Design Example

The effects that are caused by some errors are more serious than effects caused by other errors. We shall, in what follows, illustrate the results obtained using CCLTRACE for two CCL design examples. One of these is a CCL with a singlet focusing lattice. The other design example is based on a doublet lattice. Both design examples, described in a companion paper[3], accelerate 25 mA of H^- ions from 70 to 600 MeV. $E_0T = 6.5$ MV/m, and the phase advance per period is 70° for both of the 1284-MHz CCLs being considered. Probability distributions were generated from a set of 100 traces for each error condition described. The beam edge was assumed to extend to a distance of three times the rms width, (3σ).

Error Estimates for CCL with a Singlet Focusing Lattice

Each of the 66 tanks consists of 20 cells. The 6-cm-long quadrupole (quad) singlets are centered in the 5 $\beta\lambda/2$ space between tanks, and the gradients range from 3.41 to 4.45 kG/cm to maintain the 70° zero-current phase advance. Bore diameter is 2.54 cm.

The types of errors included in this study were magnetic quadrupole displacements, quad tilts (pitch and yaw), quad rotations (roll), quad gradient errors, and tank displacements. The gradient errors cause the beam to become mismatched and hence to oscillate in size. Quad rotations mix the x and y motions and cause an effective emittance growth in the x-x' and y-y' phase-space projections. The other types of errors cause the beam to oscillate about the CCL axis with an amplitude that depends on the random errors chosen for the misalignments. All of these errors cause the beam to come closer to the tank bore and can result in particle loss.

One measure of the effect of these errors is the bore filling factor. For a given set of random errors, at some point along the CCL (at 3σ, for example) the beam edge will come closest to the tank bore. The distance from the CCL axis to this point on the beam edge will be denoted by r_{max}. The maximum filling factor, f_{max}, is defined to be r_{max} divided by the bore radius. A value of 1 for f_{max} therefore denotes beam scraping at the 3σ level.

The probability distributions of f_{max} obtained when the error tolerances on quad displacements were 0.002", 0.004", and 0.006" are shown in Fig. 1. Displacement errors of 0.002" seem to have an insignificant effect on f_{max}. Even with a 0.004" tolerance, there is a 90% probability that f_{max} will be less than 0.6. The beam is very insensitive to quadrupole pitch and yaw errors. A tolerance of

*Work supported and funded by the U.S. Department of Energy, Office of the Superconducting Super Collider.

50 mrad caused no effect on f_{max}. Also, tank displacement errors with a tolerance of 0.010" caused an insignificant effect on f_{max}.

The probability distributions of f_{max} produced by error tolerances of 1%, 2% and 5% in the quad gradients are shown in Fig. 2. A 1% tolerance has no effect on f_{max}; a 2% tolerance gives a 90% probability that f_{max} will be less than 0.6; a 5% tolerance is unacceptable.

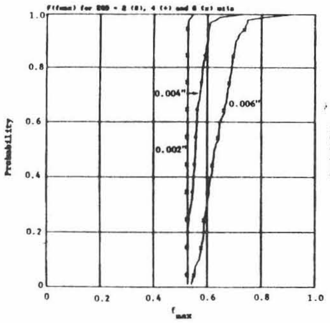

Fig. 1. Probability distribution of f_{max} (r_{max} + bore radius) for random quad displacement errors within ±0.002", 0.004", and 0.006" for the singlet design example.

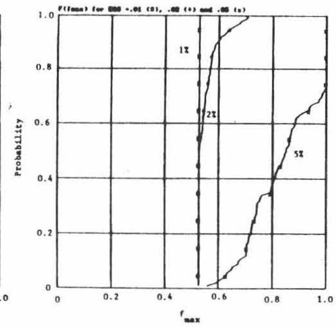

Fig. 2. Probability distribution of f_{max} (r_{max} + bore radius) for random ±1, 2, and 5% quad gradient errors for the singlet example.

The probability distribution for f_{max} produced by a combination of errors ± (0.004" quad displacements, 5-mrad quad tilts, 1° quad rotations, 2% quad gradient errors, and 0.010" tank displacements) is shown in Fig. 3. For this combination, there is a 95% probability that f_{max} will be less than 0.8.

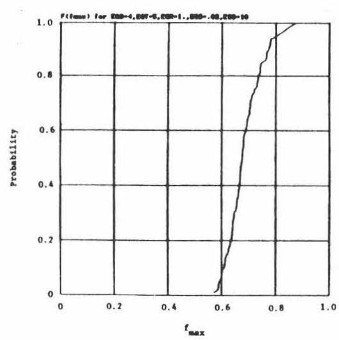

Fig. 3. Probability distribution of f_{max} (r_{max} + bore radius) for a combination of random errors for the singlet lattice, as described in the text.

Figures 4 and 5 show the projections of the equivalent uniform beam (total width is equal to $\sqrt{5}$ times the rms width) on the x, phase and energy axis when there are no errors (Fig. 4) and when there is a particular set of random errors (Fig. 5). Figure 4 shows that the beam is well matched and on axis. Figure 5 shows the beam oscillating about the axis and becoming somewhat mismatched (on the x axis). The error tolerances used in producing Fig. 5 were 0.004" quad displacements, 0.010" tank displacements, 2% quad gradient errors, and 1° phase errors.

Error Estimates for CCL with Doublets Between Tanks

Each of the 54 tanks consists of 24 cells having a bore diameter of 2.0 cm. Quadrupole doublets are centered in the space between tanks. Each doublet

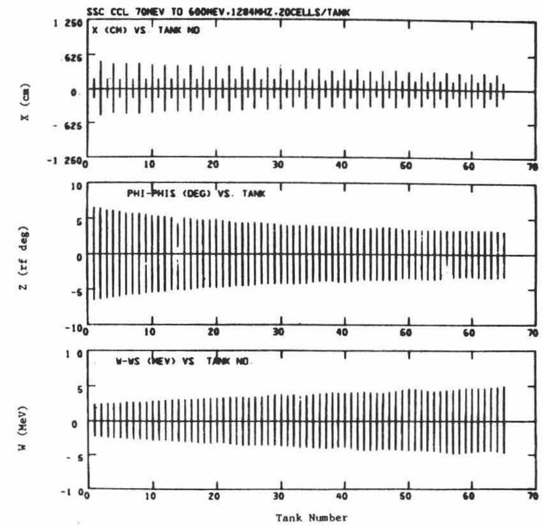

Fig 4. Beam size of singlet lattice with no errors.

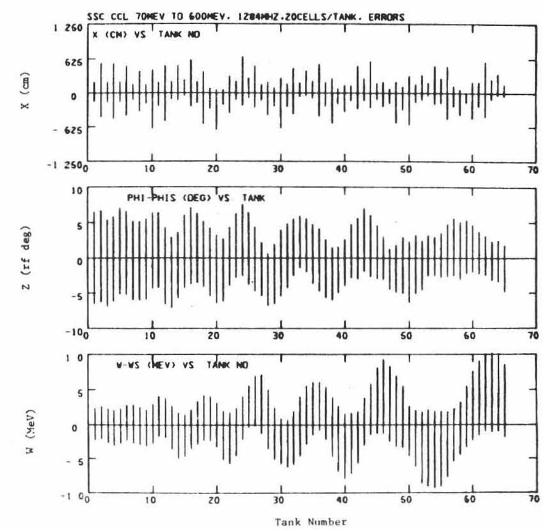

Fig. 5. Beam size of singlet lattice with a combination of random errors within ± -- 0.004" quad displacements, 0.010" tank displacements, 2% quad gradient errors and 1° phase errors.

consists of two 15.3-cm-long quadrupoles with 21.3 cm between quad centers. The quad gradients range from 2.67 to 4.94 kG/cm to maintain the 70° zero-current phase advance per period.

The types of errors included were doublet displacements, doublet tilt (pitch and yaw), doublet rotation (roll), and doublet gradient errors. In general, systems of doublets are less sensitive to displacements and rotations, but much more sensitive to tilts. The axis of the doublet is defined to be the straight line passing through the center of each of the two quadrupoles. Each quadrupole pair for a given doublet is assumed to have perfect relative alignment. The tilt angle is the angle between the doublet axis and the reference axis.

The probability distributions for f_{max} produced by 0.005", 0.010", and 0.015" doublet displacements are shown in Fig. 6. Error tolerances between 0.005" and 0.010" appear to be acceptable. The sensitivity of f_{max} to doublet tilt errors is given by the probability distributions shown in Fig. 7 for tilts of 0.25, 0.50, and 0.75 mrad. The tolerance on doublet tilt errors should be less than 0.50 mrad. Similarly, Figs. 8 and 9 show that doublet gradient errors of 2% and doublet rotation errors of 2° should be acceptable. These latter two tolerances should be easy to meet.

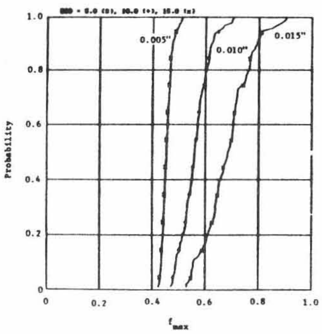

Fig. 6. Probability distribution of f_{max} for ±0.005", 0.010", and 0.015" random doublet displacement errors.

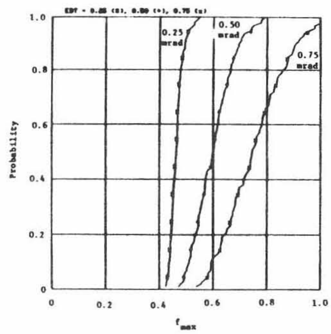

Fig. 7. Probability distribution of f_{max} for random doublet tilt errors of ±0.25, 0.50, and 0.75 mrad.

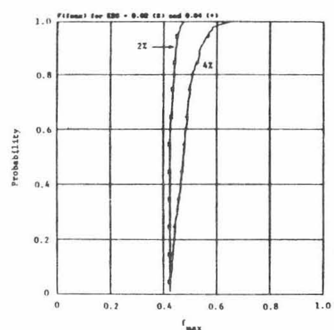

Fig. 8. Probability distribution of f_{max} for random doublet gradient errors of ±2% and 4%.

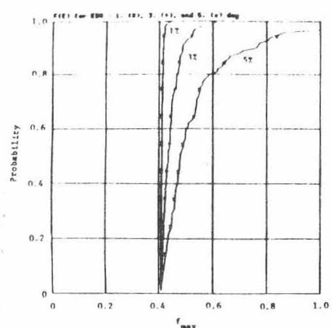

Fig. 9. Probability distribution of f_{max} for random doublet rotation errors of ±1°, 3°, and 5°.

A probability distribution for f_{max} produced by a combination of doublet errors (0.010" displacement, 0.5-mrad tilt, 3° rotation, and 2% gradient errors) is shown in Fig. 10. All of these tolerances are probably higher than would be accepted or could be achieved.

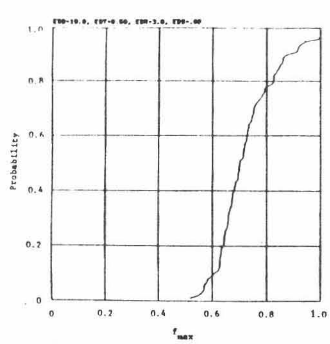

Fig. 10. Combination of doublet random errors within ± -- 0.010" displacement, 0.5-mrad tilt, 3° rotation, and 2% gradient errors.

Figures 11 and 12 show the x, phase and energy projections along the CCL for no errors (Fig. 11) and for a combination of errors (Fig. 12). The error tolerances used in producing Fig. 12 were 0.010" doublet displacements, 0.5-mrad tilt, 0.010" tank displacements, and 1° phase errors.

Conclusion and Recommendations

The CCLTRACE program is a useful tool for estimating the effects of various alignment and field strength errors in a CCL. Tank displacements of 0.010" should be relatively easy to achieve and should have no significant effect on the beam. Quadrupole displacements should be less than 0.004". Quadrupole gradient errors should be less than 2%, and quad rotations should be less than 0.5°. If doublets are used instead of singlets, the acceptable displacements can be between 0.005" and 0.010", and doublet rotations of 2° would not be serious. The tightest tolerance is on the doublet tilt, which should not be much larger than 0.50 mrad.

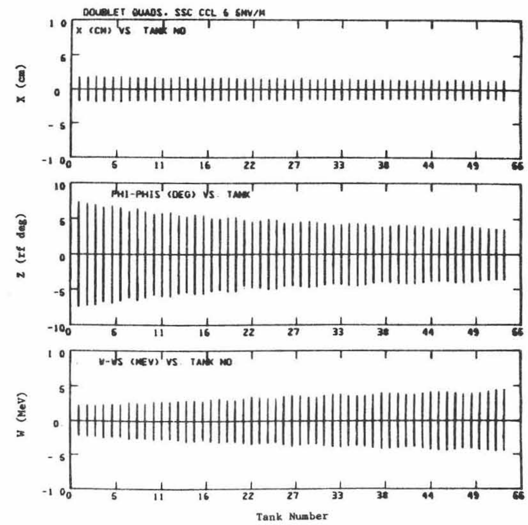

Fig. 11. Beam size of doublet lattice -- no errors.

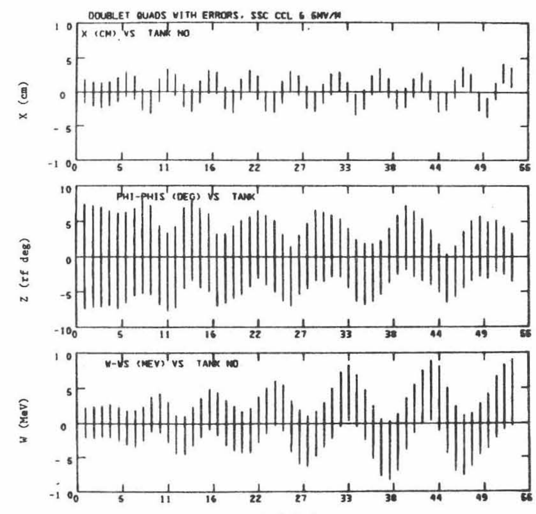

Fig. 12. Beam size of doublet lattice with combination of random error conditions within ± -- 0.010" doublet displacements, 0.5-mrad tilt, 0.010" tank displacements and 1° phase errors.

References

1. K. R. Crandall, "TRACE 3-D Documentation," Los Alamos National Laboratory report LA-11054-MS.
2. K. R. Crandall, "Error Studies Using PARTRACE, a New Program that Combines PARMILA and TRACE 3-D," Linear Accelerator Conference, Williamsburg, VA, October 3-7, 1988.
3. R. W. Garnett et al., "A Comparison of Beam Dynamics Solutions for the SSC 1284-MHz CCL," Linear Accelerator Conference, Albuquerque, NM, September 10-14, 1990.