DESIGN STUDIES OF SSC COUPLED CAVITY LINAC

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Abstract

The SSC coupled cavity linac (CCL) will be a side coupled structure operating at 1284 MHz to accelerate a nominal 25 mA H^- beam from 70 MeV to 600 MeV. We present results of both cavity design and beam dynamics studies. Each accelerating cavity is optimized by SUPERFISH; coupled cavity characteristics in the region of low-, mid- and high-energies are checked by MAFIA-3D. MAFIA-3D was also used to design the bridge coupler systems. The beam dynamics and error analysis are simulated by CCLDYN and CCLTRACE. Possible future upgrade of the CCL to 1 GeV is also discussed.

I. INTRODUCTION

The CCL provides most of the energy gain of the SSC linac. It is the least expensive per meter to fabricate, and provides the highest accelerating gradient. The side coupled type was chosen because of extensive experience at other laboratories such as LAMPF and Fermilab[1].

The SSC CCL preliminary design consists of 10 modules, each module contains 6 tanks which are resonantly coupled together by 5 bridge couplers. Each module is powered by one 20 MW klystron connected to the central bridge coupler. There will be one electromagnetic quadrupole after each tank to form a FODO structure. The conceptual layout of one typical CCL module is shown in Fig.1. In the following sections we will separately discuss cavity design and beam dynamics.

II. DESIGN OF ACCELERATING AND COUPLING CAVITIES

Each CCL tank is formed by brazing together 20 or 22 identical accelerating cells and 19 or 21 identical coupling cells. Every accelerating cell in a tank has the same length of $\beta\lambda/2$, where β corresponds to the mean energy of the tank. The length of each coupling cavity is chosen to be 65% of that of the accelerating cell. The geometry of coupling cells should be as simple as possible since it contains almost no field. They are cylindrical (R=5 cm) with two end posts for frequency fine tuning.

The geometry of accelerating cavities must be carefully designed to optimize the shunt impedance. SUPERFISH was used for this optimization. By adding capacitive loading to the center of the cavity by means of nose cones the electric field may be concentrated in the region of the beam and the transit time factor may be increased. These nose cones can also be used to fine tune the TM010 frequency. By curving the outer wall of the cavity the Q value may be increased, also improving the shunt impedance. To further reduce peak surface field which occurs at the nose cone, we adopted a double-radius nose-cone design. By enlarging the outer radius of the nose cone, the peak surface field is restricted to 32 MV/m (1.0 Kilpatrick). This corresponds to an effective on-axis accelerating gradient of 6.66 MV/m. We also chose to have the same outer radius (R=8.5 cm) and same nose cone curvatures for all accelerating cavities. The inner beam pipe radius is 1.25 cm from module 1 through 6, and is reduced to 1 cm after module 6. A typical accelerating cavity cross section is shown in Fig.2.

The SUPERFISH calculation neglects the effects of coupling slots. The actual frequency will be lower than calculated. Therefore we must design f(SUPERFISH)=1284 (MHz)+Δf, where Δf is determined from LAMPF and Fermilab data, scaled to our frequency.

The nearest-neighbour coupling k is chosen to be 5%, as a compromise of keeping high shunt impedance and minimizing the field droop caused by power flow losses. MAFIA-3D was used to calculate k. The simplest geometry we simulated includes one full accelerating cavity and two half coupling cavities, as shown in Fig.3. For this geometry we obtain four frequencies: f_o, $f_{\pi/2}$, $f_{\pi/2,\text{coupling}}$ and f_π. To eliminate the stop band, we must adjust the nose of the accelerating cell and posts of the coupling cells to bring $f_{\pi/2} = f_{\pi/2,\text{coupling}} = 1284$ MHz. We also need to adjust the length of the coupling slot to obtain the correct f_o and f_π. Then $k = (f_{\pi/2}/f_o)^2 - 1$. 3-D simulations were carried out for cavities in the low-, med- and high- energy end. Reasonable agreement has been found with SUPERFISH. Aluminium cold models to bench mark the designs for these tanks are under construction.

III. CCL BRIDGE COUPLER DESIGN

In order to provide sufficient intertank spacing for quadrupole magnets at the low energy end of the CCL, the bridge coupler length from module 1 through 5 is $5\beta\lambda/2$. After module 5, their length drops to $3\beta\lambda/2$. This keeps the length of the bridge couplers between 21.6 cm and 37.2 cm. Let $\mathcal{R}$ be the ratio of the length to radius of the bridge cavity. Bridge couplers in modules 1 through 3, and from module 6 to 10 will have $\mathcal{R} < 3.7$. For these short cavities, no modes other than TM010 are in the pass band. Consequently, their geometry can be made very simple: each

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of them consists of only one single cylindrical cavity with two end posts.

Bridge couplers in modules 4 through 5 will have $\mathcal{R} > 3.7$. For these long cavities, f(TE112,X,Y) and f(TM011) become so low that they get into the pass band and cause mode mixing problems. Currently, there are two approaches to solve this problem: (I) (LAMPF[2] and Fermilab) resonant posts are added to the bridge cavity to shift the frequencies of those unwanted modes either completely outside of the pass band or to desired values that are "symmetric" with respect to f(TM010,$\pi/2$); (II) (L. Young at LANL) disks with large apertures are used to divide a long bridge cavity into an odd number of short cavities. These short cavities will have no mode mixing problem, all modes other than TM010 are far above the pass band. A long single cavity with many posts is not mechanically simpler than a multi-cavity bridge coupler, but is electrically more difficult to tune. After trying both approaches, we prefer multi-cavity bridge couplers. Consequently, there will be two different type of bridge coupler in the CCL, 40 short ones will be of single cavity type, 10 long ones will be of multi-cavity type. Fig.4 shows a MAFIA plot of the cross section of a five-cavity bridge coupler with end tank accelerating cavities and coupling cavities.

The coupling constant between the bridge coupler and the coupling cavity was chosen to be 10%, which is much larger than the k between accelerating cavity and coupling cavity. This will make the field level in the bridge coupler much lower than that in the accelerating cavity so that the bridge coupler consumes less power.

IV. BEAM DYNAMICS AND ERROR ANALYSIS.

The drift-tube linac (DTL) that precedes the CCL operates at 428 MHz with $(E_oT) = 4$ MV/m. The CCL has $(E_oT) = 6.66$ MV/m and operates at the third harmonic of the DTL. In order to obtain a current-independent matching condition between DTL and CCL, we need to have the initial CCL accelerating gradient $(E_oT)=4/3\approx 1$ MV/m. We then slowly ramp the (E_oT) across the first two tanks from 1 MV/m to 6.66 MV/m. Ramping is achieved by making the coupling constant $k_i > k_{i+1}$. We have simulated the CCL with 0 mA, 25 mA and 3×25 mA current and find the linac is approximately current independent.

The overall CCL is 117 meters in length and we need some mechanism to correct the misalignment errors. This is done by adding steering dipoles to the magnetic quadrupole after each module. The quadrupole lenses between modules will thus be different from those between tanks. Also the spacing between modules will be larger to accommodate the additional diagnostics and an isolation vacuum valve. There are two ways to get extra spacing between modules: either we make the magnetic focusing lattice non-periodic, or keep the magnetic lattice periodic but make the first and last tank in each module shorter. We chose to keep the magnetic lattice periodic, consequently tank no.1 and tank no.6 in each module have to be made shorter. This two tanks have 20 accelerating cells, while the others have 22. A shorter tank produces less RF defocusing force, which makes the overall system (quadrupole lenses + tank) non-periodic from tank to tank. However, the system is still periodic from module to module, therefore it is possible to find a matched beam solution. To minimize the maximum beam size and emittance growth, one should try to keep the average beam size in each tank approximately constant. A CCL generating code is first used to generate the tanks and calculate the required quadrupole strength to produce the desired phase advance ($\sigma_o = 70^o$, G=28-33 T/m in our CCL). TRACE-3D is then used to find the matching condition. Finally CCLDYN pushes particles ($\geq$1000) through the linac. Fig.5 shows the energy spread, phase spread and x-envelop of the beam from 70 to 600 MeV. There are no particle losses in the CCL and the transverse emittance growth is about 40% ($\epsilon_{\mathrm{in,rms,in}} = 0.194$, $\epsilon_{\mathrm{n,rms,out}} = 0.271$ π mm-mrad).

When realistic fabrication errors are included, using CCLTRACE, the edge of the beam should stay within 60% of the bore with 95% of confidence, as show in Fig.6.

V. SUMMARY AND DISCUSSION

In the simulation we observed 40% transverse emittance growth. It is caused by the fact that the bunch length is not small compared to the bucket length. Consequently the head and the tail of the bunch are experiencing different RF defocusing force. We are making an effort to reduce the emittance growth by reducing the bunch length.

We have simulated the CCL to 1 GeV by continuing the same module and magnetic lattice structure. Six more CCL modules (additional 80 meters in length) are needed. The beam is well behaved with no emittance growth or particle losses in this section. The future upgrade to 1 GeV will thus be straightforward since the extra tunnel length will be built during the original construction.

The physics design of the SSC CCL is basically finished. Our next stage will be the engineering design and cold modeling.

ACKNOWLEDGEMENTS

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References

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[2] J.M. Potter and E.A. Knapp, "Bridge coupler design and tuning experience at Los Alamos" Proc. of the 1972 Linear Accel. Conf. p.242.

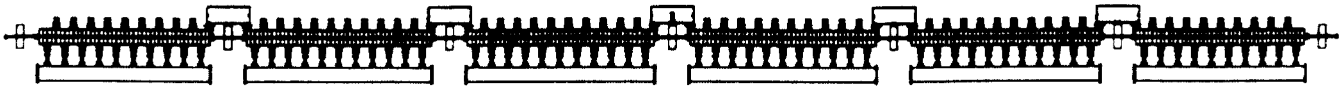

Fig.1 A typical CCL module consists of 6 tanks and 5 bridge couplers. The magnetic quadrupoles between tanks and the vacuum manifolds are also shown.

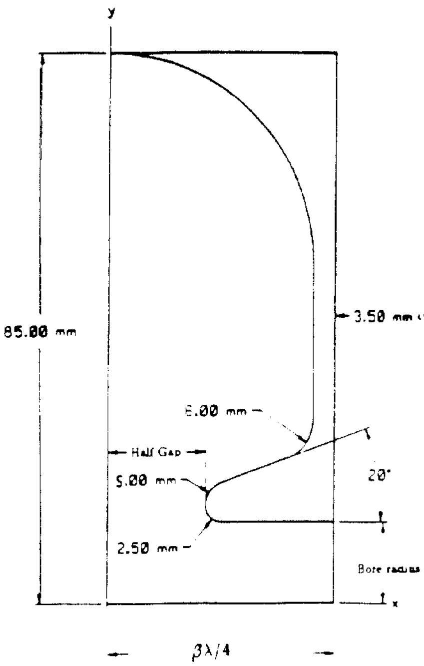

Fig.2 Cross section of a typical accelerating cavity.

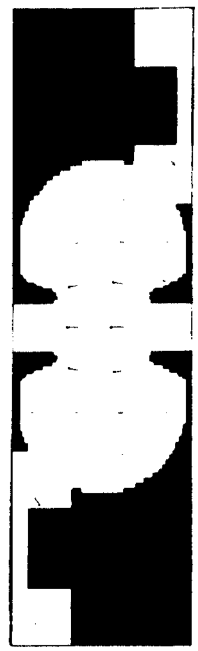

Fig.3 MAFIA simulation of one accelerating cell and two half coupling cell.

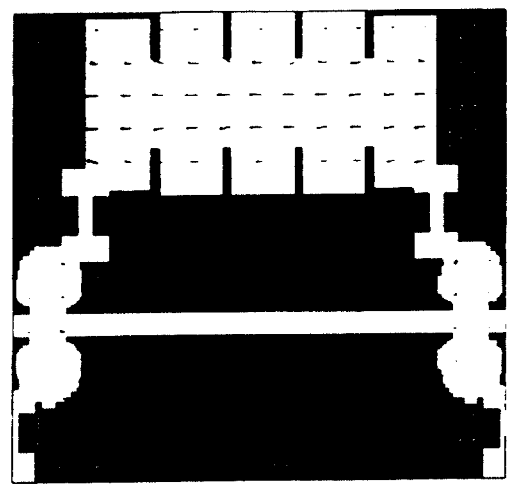

Fig.4 MAFIA simulation of multi-cavity bridge coupler.

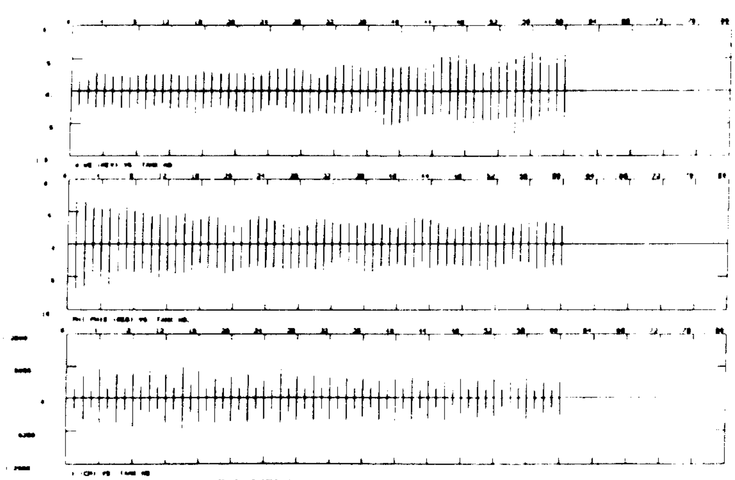

Fig.5 CCLDYN simulation results
top: energy profile
middle: phase profile
bottom: x profile.

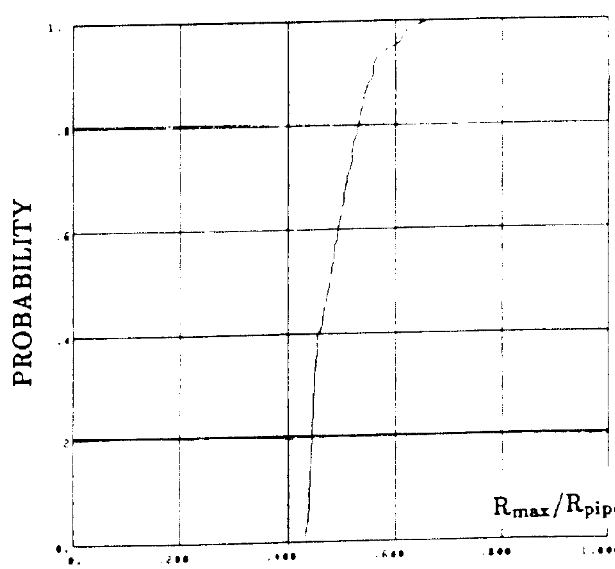

Fig.6 Results from CCLTRACE: probability vs normalized beam radius (R_{max}/R_{pipe}).