CCL Design Improvements at SSC Linac*

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Abstract

Many important changes in CCL [1] beam dynamics and cavity geometry have been made recently. The new design will bring about a decrease in emittance growth in CCL from 50% to 10%, and save of one klystron station. RF performance of the CCL has also been improved.

1. INTRODUCTION

SSC Linac provides a 600 MeV H$^-$ beam at nominal current of 25 mA for injection into the LEB. The Linac consists of an ion source (0-35 keV), a 428 MHz RFQ (0.035-2.5 MeV), a 428 MHz DTL (2.5-70 MeV) and a 1284 MHz CCL (70-600 MeV). The entire linac length is about 150 m, in which the CCL length is about 112 m. The CCL provides most energy gain of the linac, and the end-to-end simulation show that most of the emittance growth could also happen in the CCL.

2.PREVIOUS DESIGN AND PROBLEMS

In the previous design, the CCL consisted of ten modules; each module was powered by one 20 MW klystron. There were six tanks in each module with 22/20 accelerating cells per tank. The design philosophy was to keep the magnetic focusing lattice periodic. In order to provide additional space between modules for beam diagnostics, the first and the last tank in a module had to be made shorter and thus only had 20 accelerating cells. The field gradient EoT in the first two tanks of module one was ramped from 1 MV/m to 6.66 MV/m and then EoT was kept constant through out the rest of the CCL. The purpose of ramping was to make the CCL performance current independent. Because the beam size was bigger in the first six modules of the linac, the bore radius of the CCL was 1.25 cm for module one to module six, and then reduce to 1.0 cm after module six.

Making accelerating tanks with different number of cavity is very undesirable. Although the transverse external focusing is periodic, the transverse RF defocusing and the longitudinal focusing are both non-periodic. Simulation results show that as a well matched beam propagates through the linac, it oscillates longitudinally. This oscillation couples to the transverse motion, causing quite large emittance growth (>50%). The end-to-end simulation also show that ramping the field at the beginning of the linac has almost no effect on current independency with our design parameters. Finally, tanks with 22 or 20 accelerating cells are considered too long; it produces rather strong RF defocusing and large longitudinal phase slip in a tank. Consequently the beam size is large even with maximum allowable transverse focusing; also the synchronous phase must be -30^0 or more. Because of the ramping, EoT was very low in the first two tanks, the first module needed only 11 MW power. Also most other modules needed only 13 MW power. For klystrons that are capable of producing 20 MW power, this was very inefficient.

3. NEW DESIGN: BEAM DYNAMICS

To improve the beam dynamics one should: (a) make the focusing system periodic both in transverse and longitudinal direction; (b) reduce the transverse beam size. This means all tanks should be made with the same number of cavities, and number of cavities per tank should be reduced to 16 for shorter tanks. Shorter tank will not only allow stronger transverse focusing per unit length thus reduce the beam size, but also result in smaller phase slip, so the synchronous phase can be increased from -30^0 to -25^0, thus acceleration efficiency can be increased. Smaller beam size will require smaller bore size, which improves shunt impedance. With higher acceleration efficiency and better shunt impedance, it is possible to save one whole klystron station. In the new design, only 9 klystrons (thus only 9 modules) instead of 10 are needed for the CCL system. Each module now contains 8 tanks with 16 accelerating cells per tank. Ramping of EoT is abandoned thus the acceleration efficiency is improved further. The EoT is 7.2 MV/m in the first module and then slowly reduced to 6.55 MV/m (see Fig. 1), this makes the power dissipation in each module approximately the same (16 MW), which yields the maximum power efficiency. The inter module spacing is now the same as inter tank spacing, so the focusing system is completely periodic. All focusing magnets are shifted toward low energy side so that the extra space can be used for beam diagnostic devices. In contrast to old design where diagnostic devices only exist after each module, in the new design we have one diagnostic box after each tank, since most inter tank space is enlarged to over 40 cm (see Fig. 2). The CCL length, however, is the same as before so there is no additional cost on the structure. Simulation show the emittance growth of the CCL is now reduced to less than 10%.

4. NEW DESIGN: CAVITY GEOMETRY

In the old design the outer radius of all accelerating cavities was the same (R_{acc}=8.5 cm). This does not make fabrication of the cavities much easier, but does give up some RF performance of the cavities in high β region.Figure 3 shows effective shunt impedance (ZT^2) vs. G (gap width) for different β . As β increases the peak of the curves moves right. Accordingly, the outer radius of the cavity must increase to keep the frequency of the cavity constant. A region good for operation is in the right of or at the peak, where a lower shunt impedance trades a lower maximum surface field. In the old design some operation points at high β go to the left of the peak. In the new design Racc is 8.5 cm for module 1 to 7, but increases to 8.6 cm for module 8 and 9. This reduces the peak surface field by 10% due to according increase in gap width.

As mentioned above, in the old design the beam aperture of the cavity is 2.5 cm for module 1 to 6, and 2.0 cm for module 7 to 10. In the new design due to the smaller beam size the aperture throughout the CCL is 2.0 cm in diameter.Reducing aperture in diameter from 2.5 cm to 2.0 cm increases ZT^2 by 12% for first six modules.

Several changes in the coupling cell geometry are made. First, the diameter of the coupling cell is enlarged by 2 cm (from 10 cm to 12 cm). Secondly, the length of the coupling cell is kept the same within one module, but increases from module to module These changes make the frequency less sensitive to geometry error. The frequency shift of the coupling cell under vacuum due to end wall deflection is described by the following formula

$$\frac{df}{f} = -\frac{\varepsilon E^2_{max}\Delta V}{8U_e} \Rightarrow \frac{\Delta V}{VG^2}.$$

Increasing the cell volume V, and the gap width G in the new design will reduce the frequency shift caused by vacuum. In addition, each coupling cell is identical in one module, the tuning is easier by dealing with only one frequency shift, rather than many different frequency shifts from tank to tank in per module.

The cross section of the end posts in coupling cavities is changed from single curvature to double curvature, as show in Fig. 4, this geometry reduces the peak surface filed as well as the possibility of multipactoring.

The coupling between the accelerating cell and coupling cell was chosen to be 5% throughout the CCL. Our new studies show that this value is too small,especially for the low energy side. Increasing coupling will (1) reduce power flow phase shift; (2) reduce field and power droop from the power feeding point; (3) increase the mode spacing near the operating mode; (4) reduce the field tilt sensitivity; (5) reduce the field level in the coupling cavities; (6) reduce the transient beam loading effect. However, for each 1% increasing of coupling, there will be about 3% drop in shunt impedance. After numerous LOOP simulations, we decided to increase the coupling to 7% for module 1 through 5, and 6% from module 6 to 9. This change will improve the stabilities of the structure with the expense of a few percent of shunt impedance lose.

5 BRIDGE COUPLER

Bridge couplers are used to connects the eight tanks in a module together to form a single RF structure so that one klystron can power the whole module. They provide spaces for placement of focusing elements and beam diagnostic devices; they can also be used to correct the filed droop. A good bridge coupler should have the following features: (1) provide zero power flow phase shift; (2) provide strong coupling; (3) small power dissipation; (4) easy fabrication. Our bridge coupler lengths are from 30 to 46 cm. The TM010 single cavity bridge coupler used in LAMPF and FermiUpgrade are having severe mode mixing problems for 46 cm long bridge coupler, so extensive turning are needed to get zero power flow phase shift, also the coupling is very weak for this type of bridge coupler. Three types of bridge couplers are proposed for consideration, the single cavity TM012 bridge coupler, multi-cavity electrically coupled bridge coupler (5 cavities coupled through central iris and one is used in Japanese Hadron Project Linac [2]) and multi-cavity magnetically coupled bridge coupler (5 cavities, coupled through coupling slots and a new type of bridge coupler proposed by C. G. Yao at SSC [3]). MAFIA simulations and cold model measurements are made for all three candidates. The TM012 bridge coupler provides

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excellent power flow capability, but still have mode mixing problem; the electrically coupled bridge coupler works very well if it is relatively short, but for the extremely long ones, the coupling can not be too strong or the TE11 will mix into the pass band. The magnetically coupled bridge coupler, which has minimum mode mixing problems and provides maximum coupling for the long structure, is chosen. Further magnetic coupled bridge coupler cold model are under construction.

6. SUMMARY

The new design of the CCL results significant improvement in beam dynamics as well as in the RF performance. It also saves one klystron RF station which yields over one million dollars saving. The number of bridge coupler does increased from 50 to 63, but the total CCL length is not increased.

The first module of the CCL is under construction and is scheduled for completion by the end of this year

7. REFERENCES:

[1] J. M. Watson, The SSC Linac. p. 31, Proceedings of the 1990 Linear Accelerator Conference.

[2] Y. Morozumi, et al., Multi-cavity Bridge Coupler, p.153, Proceedings of the 1990 Linear Accelerator Conference.

[3] C. G. Yao, C. R. Chang and W. Funk, A Novel Bridge Coupler for SSC coupled Cavity Linac, Proceedings of the 1992 Linear Accelerator Conference, Canada.

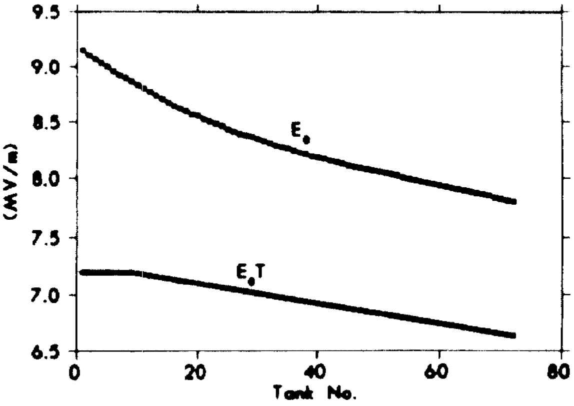

Figure 1. Field in tank vs. tank number

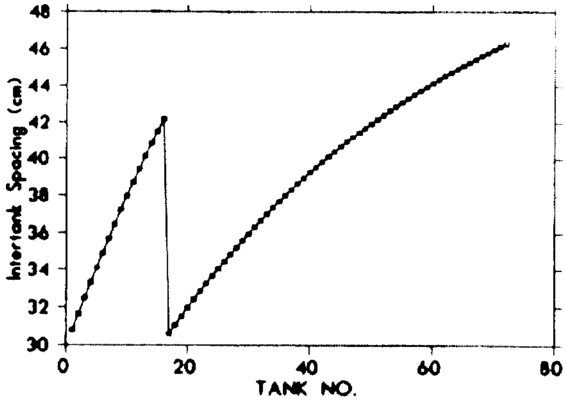

Figure 2. Intertank space vs. tank No.

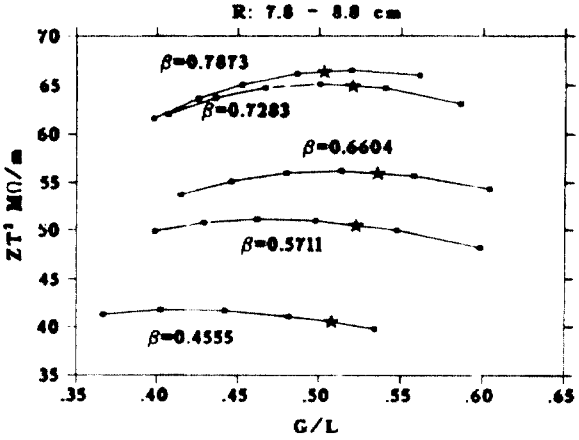

Figure 3. Effective shunt impedance ZT^2 vs. gap width G for different β.

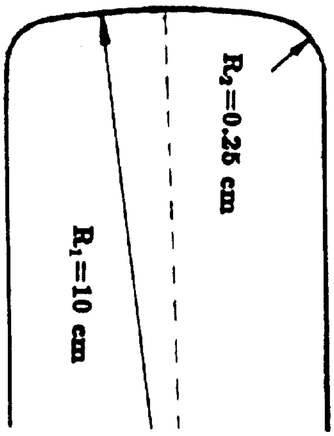

Figure 4. cross section of post in coupling cell.