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COMPUTER SIMULATION AND COLD MODEL TESTING OF CCL CAVITIES

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Abstract

The SSC coupled-cavity-linac (CCL) consists of nine modules with eight tanks in each module. Multicavity magnetically coupled bridge couplers are used to couple the eight tanks within a module into one RF resonant chain. The operating frequency is 1282.851 MHz. In this paper we discuss both computer calculations and cold model measurements to determine the geometry dimension of the RF structure.

I. Introduction

The SSC CCL cavities are designed in house and fabricated by the Institute of High Energy Physics (IHEP) in China. One of our major tests is to provide the accurate cavity dimensions for machine fabrication. In the past, the cavity dimensions were determined by cold model experiments only, because at that time, no computer code had enough accuracy for such complicated, highly non-axial geometric structures. Our CCL contains 72 accelerating tanks and 63 bridge couplers. Producing cold models for each tank and bridge coupler would be an extremely expensive and time consuming task. We have developed new methods that combine modern codes like MAFIA, SUPERFISH and HFSS and are able to produce cavity dimensions that are correct within a few MHz error. Of course, cold models for the low-, mid- and high- energy end are made and are used to bench mark these codes.

II. Determination of Accelerating Tank Dimensions

Each CCL tank contains 16 identical accelerating cavities and 15 identical coupling cavities. The structure can be treated as infinitely long if the end cavities are properly tuned. In 3-D MAFIA simulation we include one full accelerating cavity and two half coupling cavities and with proper terminations at symmetric planes z_{min} and z_{max} we can simulate an infinitely long structure. Fig. 1. shows the physical boundary and boundary simulated by MAFIA. We can see "steps" on the boundary because the code uses many "cubics" to produce an approximation for the actual smooth surface. This is a major source of inaccuracy in the solution and can not be completely removed for a finite number of mesh used. We have built

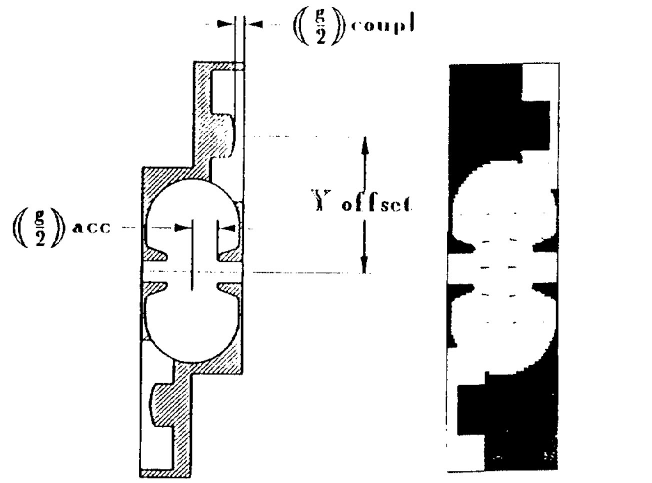

Figure 1: (a) Physical boundary of one accelerating cell and two half coupling cells, (b) boundary simulated by MAFIA

cold models according to the exact dimensions predicted by MAFIA and the measured frequency can be as much as 15 MHz different from the calculated frequency. The agreement on the coupling constant, k, on the other hand, is quite good, as shown in Table 1. The frequency change is very sensitive to the dimension change in the nose region. The geometry of the nose is too complicated to be accurately described by MAFIA. But the slot region is described very well. SUPERFISH with triangular meshes can give very good descriptions of arbitrarily complicated boundaries and the error of calculated frequency is usually smaller than 1 MHz. However, it is a 2-D code and cannot predict the effect of coupling slots, which is not a small effect for 7% coupling. D.A. Swenson proposed a way that combines the SUPERFISH and MAFIA and can eliminate the shortcoming of each code. The procedures are: (1) let MAFIA calculate the coupling constant and the effect of the coupling slots which produce a frequency drop Δf to the accelerating cell; (2) let SUPERFISH determine the nose gap, $(g/2)_{acc}$, of the unslotted cavity to produce a resonant frequency of $f_{operation} + \Delta f$. The cavity with slots should then resonant at $f_{operation} + \Delta f - \Delta f = f_{operation}$. The Δf produced by coupling slots can be calculated by two MAFIA runs: (1) calculate the accelerating cell frequency with coupling slots, f_{slot}, and (2) use the same mesh configuration to calculate accelerating cell frequency without coupling slots, f_0. Then $\Delta f = f_{slot} - f_0$. Since the mesh configurations are the same for two runs, the error of f_{slot} and f_0 due to the same crude description of

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Y_{off} [cm]	k: Cold Model	k: MAFIA	Difference
11.18	7.904%	7.989%	-0.085%
11.93	4.895%	4.801%	0.094%
12.93	1.507%	1.638%	-0.13%

Table 1: Comparison of coupling constant from cold model and MAFIA

Y_{off} [cm]	Δf_{exp}	Δf_{cal}	Difference
11.18	38.168	38.725	-0.557
11.93	22.505	22.745	-0.240
12.93	6.310	6.295	-0.015

Table 2: Comparison of Δf (Unit: MHz) measured by cold model and calculated by MAFIA and SUPERFISH

the nose should be also the same and therefore the error is subtracted out in Δf. If Δf can be accurately determined, $(g/2)_{acc}$ can be accurately determined. The dimensions of coupling cavities can be calculated in a similar way. To test the validity of this method, we build cold models with different Y_{off} and compare the measured and computed values of k and Δf. Table 1 shows the results of comparison of k and Table 2 shows the comparison of Δf.

The surprisingly good agreements give us confidence with the method and we have generated the rest of tank dimensions entirely on computers. We did make two additional sets of cold models on the med- and high-energy end and the agreements with simulation results are consistently good.

III. Determination of Bridge Coupler Dimensions

Fig. 2 shows the geometry of a five-cell bridge coupler with three identical middle cells and two identical end cells. Two end posts as frequency tuners are provided for end cells but not for middle cells. The physics of this type of bridge coupler are described previously[1,2]. The total length of the bridge coupler grows with the inter tank space which is proportional to $\beta\lambda$. For 63 bridge couplers, the length of the middle cells can only be 7cm, 8cm or 9cm, but the length of the end cells will have 63 different values. Again, the three middle cells can be treated as a part of an infinitely long structure if the two end cells are properly tuned. We thus separately determine the dimensions for middle cells and for end cells.

For middle cells, MAFIA was first used to optimize the geometry of the coupling slots. Because middle cells only have three possible lengths, cold models were built for all three cases. The coupling slots on adjacent disc are rotated by 90^o to reduce direct coupling. Half cell termination were used in the experiment. Since this will create images in the end cells that do not have 90^o rotations, it does not represent an infinite long structure. However, as the cavity chain gets longer, the end cell error effect gets smaller and the structure approaches to an infinitely long structure. With a few measurements, the asymptote can be obtained and it gives the desired frequency value. The radius of these center cavities can then be determined.

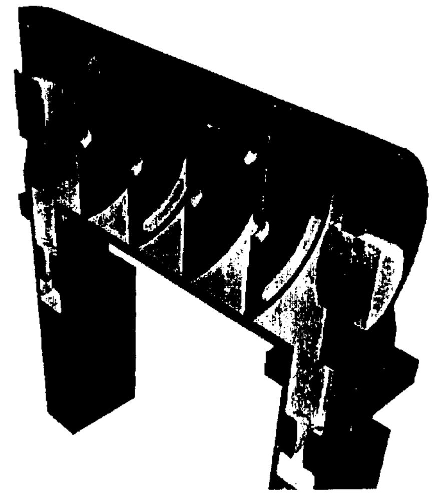

Figure 2: Geometry of Magnetically Coupled Bridge Coupler

Bridge coupler end cells are more complicated. They do not have any well defined symmetric plane and can not be treated as a part of an infinite structure. MAFIA simulation on the bridge end cavities produce quite large errors because some artificial symmetric planes must be assumed to terminate the boundary. The end cell dimensions are completely determined by experiment. Since there are no well defined symmetric planes, no artificial terminations should be used. In the cold model measurement, one must include the entire 5-cell bridge cavity, the two coupling cavities under the bridge, and tank end cells and a few accelerating cavities. All accelerating cavities and bridge center cavities are fabricated at the correct dimensions. Bridge end cavity frequencies are adjustable by end posts. To determine the post length, one should first short out all other cells except the bridge end cell, tank end cell and the coupling cell between them. Adjusting the bridge end cell and tank end cell frequencies by varying the post lengths until the two cavity frequencies are both equal to 1282.851 MHz. At this point, the field level in the coupling cavity is zero. Repeat same procedure for the other bridge end cell. Finally, let all cavities couple together by removing shorting tools and measure the $\pi/2$ mode frequency. The $\pi/2$ frequency should be very close to the desired operation frequency. Adjust the two end posts equally to bring the $\pi/2$ mode frequency to the exact value. The post lengths are now at the correct value. We made three bridge cold models for the low-, med-, and high-energy end. Dimensions for those bridge end cells in between were obtained by interpolation.

IV. Determination of Coupling Iris between Wave Guide and Power Cell

RF power is sent from waveguide to a CCL module through a coupling iris at the center bridge coupler power cell. The dimension of this coupling iris must be determined to provide the correct coupling ($\beta = 1.0$) from the waveguide to one CCL module. Normally this iris is cut last when the entire module is assembled, as is the case for LAMPF and Fermilab. However, for our situation, it is desirable to know the approximate iris size in advance. There are two reasons. (1) In LAMPF and Fermilab each coupling iris only needs to drive two to four tanks, yet it must be cut very large to provide enough coupling. In our CCL, each iris must drive eight tanks, which has at least twice as many cavities. Concern was raised whether one iris can provide enough coupling. (2) Both LAMPF and Fermi use single cavity bridge couplers. Because of its large volume, the coupling iris will not produce a big perturbation to the bridge cavity. With two end posts as frequency tuners, the power bridges do not need to be specially made so the iris can be cut as the last step. We use multi-cavity bridge couplers and the center cell has much smaller volume so the coupling iris will produce a large frequency drop δf. It is not desirable to add a tuner to the power cell due to the concern of sparking. A better solution is to reduce the power cell diameter in advance to raise the frequency back to the desired value. Thus the knowledge of iris size and the magnitude of δf is desirable.

To estimate the coupling slot dimension without the entire module assembled, we need to do some scaling. Assume coupling cavities are not excited and dissipate no power, then one module contains $N_{acc} = 128$ accelerating cavities and $N_{brig} = 21$ excited bridge cavities. The field level in an excited bridge cavity is approximately equal to half the level in an accelerating cavity so the power dissipation is $P_{brig}/P_{acc} \approx 1/4$, assuming the same Q ($Q_{Cu} \approx 11000$ for module I) value. The total power dissipation of one module is then equal to $N_{acc}+N_{brig}(P_{brig}/P_{acc}) \approx 133$ accelerating cells. In cold modeling we have one bridge coupler and two accelerating cells. From power dissipation point of view it is equivalent to $N_{model} \approx 3$ accelerating cells. Taking into account the fact that the $Q_{Al} \approx 1000$ for aluminium cold models, in order to obtain $\beta_o = 1$ for one CCL module, the equivalent β_{model} we are aiming for in the cold model measurement should be about $\beta_{model} = \beta_o \times (Q_{Al}/Q_{Cu}) \times [N_{acc} + N_{brig}(P_{brig}/P_{acc})]/N_{model} \approx 4$. β should be bigger when power dissipation in coupling cells is taken into account. To obtain the functional relation between β and slot size, a set of "plugs" with different sized rectangular irises are made and β values are measured. Some preliminary results are plotted in Fig. 3. It can be seen that β has a weak dependence on slot width but a very strong dependence on slot length. The β increase with l in a nearly exponential form, for 7cm $\leq$ l $\leq$ 9cm, so we see straight lines in a logarithmic scale. But as l increased to comparable to the height of the wave guide, the curves bend downward because the magnetic flux in the wave guide has a high density near the center but falls off toward the edge. The β value can easily exceed 4, indicating one slot should provide enough coupling to drive one CCL module.

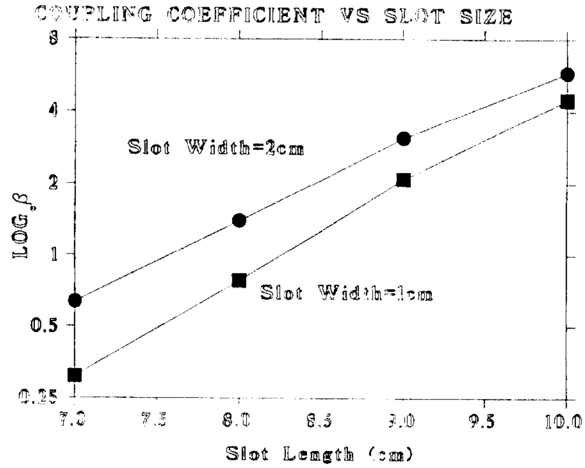

Figure 3: Measured coupling β vs slot length for slot width of 1 cm and 2 cm.

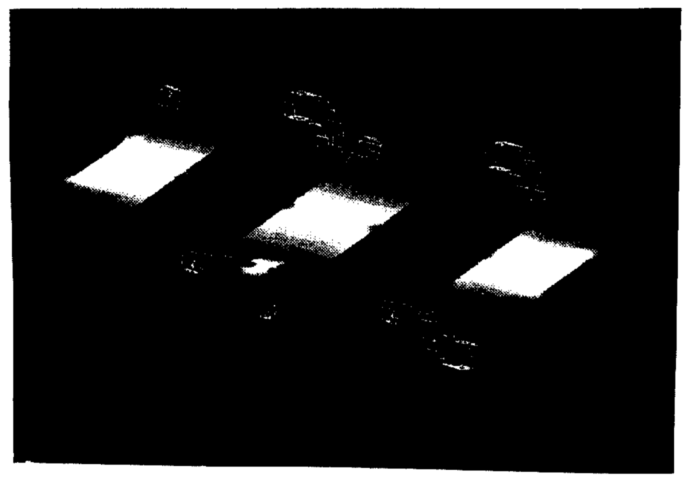

Figure 4: HFSS simulating electric field coupling from wave guide to bridge coupler

We are also doing computer modeling of the problem. The 3-D HFSS code with its powerful S-parameter solver is particularly convenient. Fig. 4 shows how the field is coupled from waveguide through iris into a five-cell bridge coupler. The simulation, however, show β increase with slot length faster than what was observed in the experiment. Further studies are needed to solve this discrepancy.

In summary, we have almost completed the entire CCL cavity dimension table and the only thing not finally determined is the dimension of the power coupling iris. Our preliminary results indicate one iris should provide sufficient coupling but more careful studies are needed to obtain its final dimension. Special thanks to Y. Goren, L. Walling, N. Yao and Y. Tang for their valuable assistance.

V. References

[1] C. G. Yao, *et al*, " A Novel Bridge Coupler for SSC Coupled Cavity Linac" , 1992 Linear Accelerator Conference, Ottawa, Canada.

[2] C. R. Chang, *et al*, " MAFIA Simulation and Cold Model Test of Three Types of Bridge Coupler", ibid.