MAFIA SIMULATION AND COLD MODEL TEST OF THREE TYPES OF BRIDGE COUPLER

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Abstract

In the new design of the SSC CCL, the total number of bridge coupler has increased from 50 to 63, and their maximum length increased from 37.2 to 46.1 cm. Choosing a bridge coupler that gives maximum coupling, minimum power flow phase shift and fabrication cost becomes important. The conventional TM010 single cavity bridge coupler used in LAMPF and FERMILAB will have severe mode mixing problem when the bridge length is over 30 cm, and the coupling is very weak. Three types of bridge coupler have been proposed: (1) TM012 single cavity bridge coupler^1; (2) electrically coupled multi-cavity bridge coupler and (3) magnetically coupled multi-cavity bridge coupler^2. This paper presents both MAFIA simulations and cold model tests results. Each bridge coupler has its unique characteristics with advantages and disadvantages, but all three are superior to the conventional bridge coupler.

I. INTRODUCTION

A good bridge coupler should have the following features: (1) zero power flow phase shift; (2) large group velocity; (3) small power dissipation; (4) easy tuning and (5) low fabrication cost. High order modes mixing into the pass band and small group velocity will cause power flow phase shift and tuning difficulties. The goal for the new bridge couplers should be (1) avoid modes other than the operating modes getting into the pass band; (2) providing strong inter-cell coupling to increasing the group velocity. We will compare the performance of the three types of bridge coupler using these two criteria. The primary tool used for this study is MAFIA.

II. SINGLE CAVITY BRIDGE COUPLERS

One advantage of single cavity bridge couplers is a reduction in the effective cell count in the CCL cavity chain thereby increases the mode spacing to the nearest modes in long structures. Also the fabrication cost of a single cavity bridge coupler should be lower and its vacuum properties should be better. Fig. 1 shows the geometry of a typical TM012 bridge coupler. It is almost the same as that of the TM010 type except its diameter is bigger so that it is the TM012 mode that is operating at the right frequency.

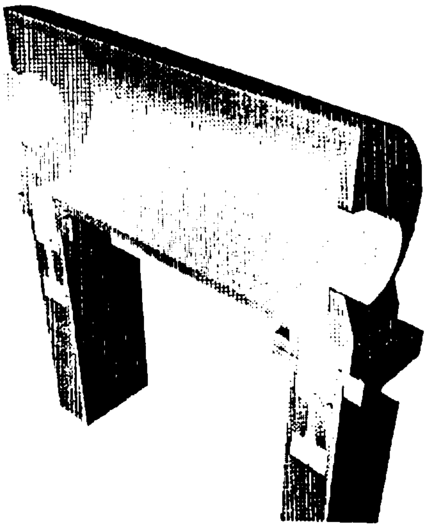

Figure 1: Geometry of TM012 Bridge Coupler

If the effect of coupling slots is ignored, it is a pure cylinder and the operating frequency for the TM01n mode can be written as $f_{01n} = \sqrt{f_{010}^2 + (kc)^2}$, where $f_{010} = p_{01}c/2\pi R$ is the TM010 mode frequency and $k = n/2L_{bridge}$. The group velocity is $v_g = df/dk = kc^2/f_{01n}$. For $n = 2$, $L_{bridge} = 40$ cm and $f_{012} = 1282.851$ MHz, we have $\beta_g = v_g/c = 0.58$, which is very big. For TM010 bridge coupler, we have $n = 0$ so $v_g = 0$. Perturbation by the coupling slots gives the TM010 bridge a non-zero group velocity, but as its length get longer, the effect of the coupling slots and the group velocity become smaller. The field distribution in a TM010 bridge coupler is almost uniform so the entire cavity wall will dissipate power. The field in a TM012 bridge coupler, on the other hand, has a sinusoidal variation with two "nodes", so power dissipation should be less.

We have made numerous MAFIA simulations on TM012 bridge couplers of different lengths (thus different diameters). For short bridge cavities ($L/D \leq 1$), mode mixing is not a problem and the TM012 type should be the best candidate. For long bridge cavities ($L/D \gg 1$), modes are distributed close to each other and mode mixing is always a concern. A cold model of $L_{bridge} = 40$ cm and $D_{bridge} = 22$ cm (which is considered long) was made. Two slug tuners on the end walls provide tuning of the TM01n modes. Here we can only summarize the simulation and measurement results. MAFIA shows that some modes in

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*Operated by the Universities Research Association, Inc. for the U.S. Department of Energy, under contract No. DE-AC35-89ER40486

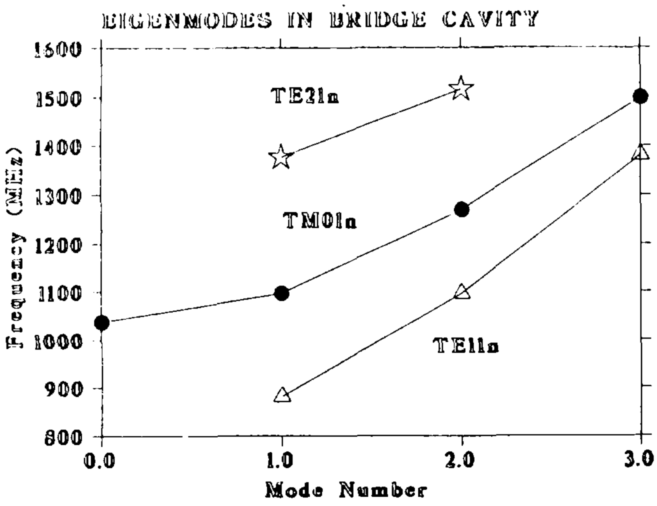

Figure 2: Eigenmodes of bridge cavity with L=40 cm and D=22 cm. Coupling cavity can couple to many of these modes

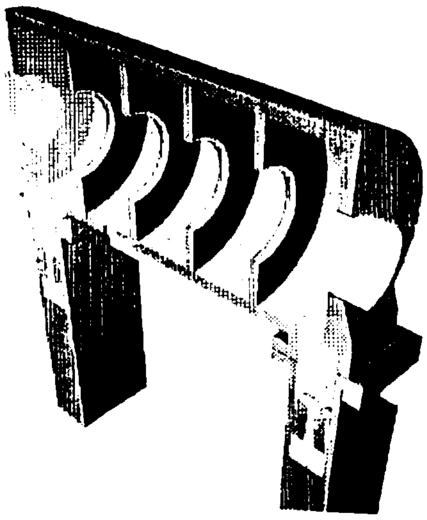

Figure 3: Geometry of Electric Coupled Bridge Coupler

the TM012 bridge cavity are neither pure TE nor pure TM, but are hybrid modes that are difficult to identify. Also the coupling cavity under the bridge coupler can couple to many neighboring modes in the bridge cavity (Fig. 2). This makes the bridge coupler difficult to tune. The mode distribution measured in the cold model agrees quite well with MAFIA results. The nearest mode to the operating mode is identified as the TE113 mode and is about 60 MHz above the operating mode. This should be far enough and we should not have mode mixing for this particular set of dimensions. However, in the cold model measurements we have not been able to obtain a zero power flow phase shift. The cause of non-zero power flow phase shift is not known and additional studies are needed. It is believed that this bridge coupler can be made to work, but requires some tuning.

III. MULTI-CAVITY BRIDGE COUPLERS

The main advantage of the multi-cavity bridge coupler is that a long cavity is divided into N+1 short cavities and the high order modes are distributed far from the pass band. Operating at $\pi/2$ mode, the structure is very stable. Only (N+2)/2 cavities dissipate power; the other N/2 cavities are unexcited. Figs. 3 and 5 show the geometry of an electrically (E-bridge coupler) and a magnetically (B-bridge coupler) coupled bridge coupler. They are both five cell disc-loaded wave guides, except one is coupled by the E field through the center apertures and the other is coupled by the B field through the coupling slots near the edge of the discs.

The three middle cavities can be considered as a part of a singly periodic structure. With $N+1$ cells the dispersion relation is $f_n = f_o/\sqrt{1+K_1\cos[n\pi/N]}$, where $n = 0, 1, 2, ...N$ is the mode number and K_1 is the nearest neighbor coupling. The $\pi/2$ mode group velocity is then $\beta_g = v_g/c = \pi K_1 L_{bridge}/N\lambda$. For fixed frequency and L_{bridge}, $\beta_g \propto K_1$. If K_1=12%, N+1=5, and $f_{\pi/2}$ =1282.851 MHz, then $\beta_g = 0.11$, which is reasonably large. For E-bridge coupler, K_1 can be increased by increasing the center aperture radius. The K_1 of the E-bridge is limited by the fact that TE111 modes may get into the pass band if the apertures are too big. For our longest bridge coupler (L_{cav}=9 cm), Fig. 5 shows how TE111 pass band frequencies change with aperture radius (MAFIA results). It can be seen that the maximum K_1 is limited to about 8%, if we want to keep TE111 mode out of the pass band.

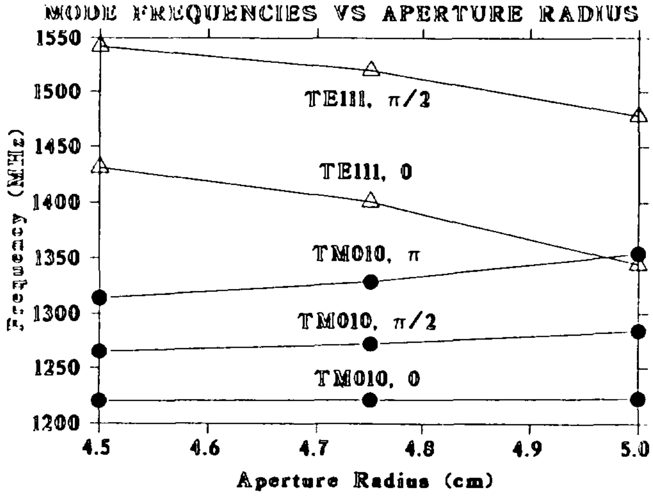

Figure 4: TM010 and TE111 Frequencies vs Aperture Radius

For B-bridge coupler, K_1 can be increased by increasing the slot length (the slot length has a first order effect on K_1 while the slot width only has a second order effect). The main factor that limits the K_1 value for B-bridge is the second nearest neighbor coupling K_2. A large $|K_2|$ will cause asymmetric dispersion curve and reduce the group velocity of the $\pi/2$ mode. Without affecting K_1, $|K_2|$ can be reduced by rotating the adjacent disc by 90° so that the

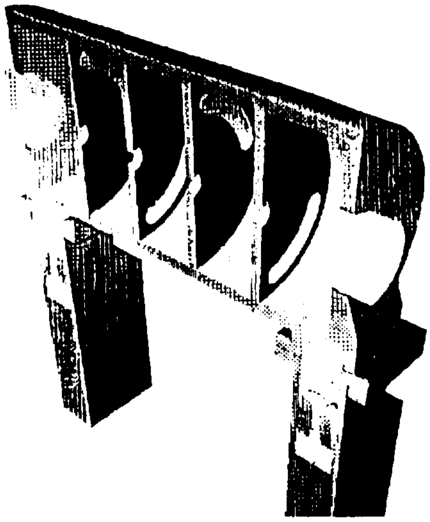

Figure 5: Geometry of Magnetic Coupled Bridge Coupler

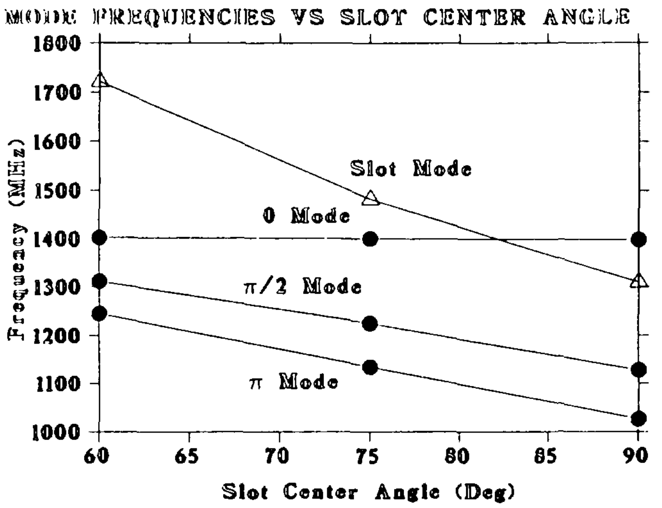

Figure 6: 0, $\pi/2$, π and slot mode frequencies vs Slot Center Angle

coupling slots on adjacent discs do not directly "see" each other. If the length of the coupling slots becomes so long that the center angle θ exceeds 90^o, then part of the slot will still directly see each other and the $|K_2|$ will increase drastically. Also if the coupling slots are too long, the frequencies of high order modes excited by coupling slots may become low enough and get into the pass band. Thus the center angle θ should always be less than 90^o, in fact we found $\theta \approx 60^o$ is a good choice for our bridge couplers. It gives sufficiently large K_1 ($K_1 \approx 13\%$ for the shortest bridge and $K_1 \approx 10\%$ for the longest bridge), $|K_2|$ is not too big and the frequencies of slot excited modes are at least 100 MHz above the top of the pass band (Fig. 6). The other high order modes are even farther away.

For B-bridge coupler, the open area of the slots is very small compared to the area of the disc. The advantage is that the high order modes are far away from the operating mode because each effective cell length is short.

	TM012	E-Bridge	B-Bridge
Group velocity	1	3	2
Mode Mixing	3	2	1
Power Dissp.	3	2	1
Fab. Cost	1	2	3
Vacuum	1	2	3

Table 1: 1=best of the three, 2=second of the three, 3=worst of the three

The disadvantage is that the vacuum property for such a closed structure will not be as good as an open structure. The E-bridge coupler, on the other hand, has quite large openings on the apertures. The vacuum will be better but the TE111 modes could be a problem. The second nearest neighbor coupling never seems to be a problem for electric coupled structure. Even for very large apertures, the dispersion curve is always very symmetric (Fig. 4).

As stated early, in a five-cell bridge coupler, only three cells (# 1, # 3 and # 5) are excited. The coupling between end cells (# 1, # 5) and the coupling cells under the bridge coupler can be about 12% - 14%, which is twice the coupling between the accelerating cell and coupling cell. The field level in the excited cells of the bridge coupler is therefore about half as that in the accelerating cell and the power dissipation is about 1/4 (each accelerating cell has about the same volume as a bridge cell). The power dissipation of one five cell bridge coupler is therefore about 3/4 of one accelerating cell, which is very small.

IV. COMPARISON

The TM012 bridge coupler has the highest group velocity among the three. The vacuum should be the best and fabrication cost should be the lowest. It should be the idea candidate for short bridge couplers. However, for long bridge couplers, mode mixing still can be a problem and additional studies are needed. The multicavity bridge coupler is more suitable for long structures. The E-bridge and B-bridge are very similar. The B-bridge is least subject to mode mixing and can provide stronger coupling and higher group velocity; but the E-bridge has better vacuum and is slightly easier to fabricate. The fabrication cost for a multicavity bridge coupler is higher, but the tuning should be easier and power dissipation should be lower. This comparison is summarized in Table 1.

V. REFERENCES

[1] D. Swenson, *et al*, " Studies of TM012 Bridge Coupler", these proceedings.

[2] C. G. Yao, *et al*, " A Novel Bridge Coupler for SSC Coupled Cavity Linac" , these proceedings.