DAMPING OF HIGHER-ORDER MODES IN A THREEFOLD SYMMETRY ACCELERATING STRUCTURE

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Abstract

We investigate a waveguide-coupled damping structure with threefold symmetry using the 2-D and 3-D MAFIA codes. Within the frequency range considered, all higher order modes except the TM011 and TE111 modes are heavily damped. Possible ways to detrap these by using asymmetric waveguides offset with respect to the accelerating cavity in the direction of the beam are studied. External Qs and resonant frequencies are calculated using recently developed computer methods.

INTRODUCTION

Much work has been done since the first workshop on Future Linear Collider held in SLAC in 1988 on the design of damped accelerating structures using various waveguide loaded cavities. Accelerating structures in which higher order modes (HOM) are damped by coupling to waveguides via radial and circumferential slots have been proposed by R. Palmer[1]. We have studied several of these damped cavities with radial or circumferential couplers and have calculated, in each instance, the external Qs and resonant frequencies of the damped structure using a theory developed by Kroll and Yu[2], based on frequencies and phase shifts for shorted waveguides. A useful extension and variation of this theory has been recently developed[3] and is also used in our evaluation.

We begin by recapitulating some results for cavities with twofold-symmetry radial or circumferential slots which have been reported previously[4]. The calculated Q for the principal transverse mode of the radially slotted cavities is between 8.7 to 13.2, depending on the waveguide cutoff frequency. Results for the Q values using the Kroll-Yu method are highly accurate and convincing, and compare favorably with those obtained with other methods[5]. In addition, the Kroll-Yu method determines the resonance frequencies accurately. A problem with the radial slot cavity is the existence of a slot mode which persistently has a lower frequency than the accelerating mode. Because it has a different symmetry from the accelerating mode, however, it can be strongly coupled out by use of a double ridge waveguide[2] having a lower cutoff frequency than the fundamental mode, without significantly damping the latter.

An advantage of circumferentially coupled cavities is the absence of any slot modes. Not restricted by clearance considerations, use of smaller irises in these cavities also helps preserve accelerating field structure and depress HOM longitudinal coupling. A potential problem of these cavities is that the lowest transverse frequency is very near the waveguide cutoff. It is important to design the structure with extreme care in order to avoid trapped transverse modes. The possibility exists that a transverse mode is trapped even when its frequency, in the absence of damping waveguides, is above the waveguide cutoff. Ideally, the waveguide cutoff frequency should be far enough below the HOM to avoid trapping, and yet be sufficiently high above the fundamental, so that the accelerating mode is well preserved[5].

Recently, Arcioni and Conciauro[6] (AC) proposed a threefold symmetric, circumferentially coupled, waveguide loaded cavity. They showed that the shunt impedance and the Q of the accelerating mode are degraded by 20% and 12%, respectively, from those of a closed cavity, while most of the HOMs were effectively damped. In this research we applied our computer method to further analyze this S-band cavity. The resonance frequencies and external Qs of the HOM for this structure were calculated. Then we studied a similar X-band waveguide loaded accelerating structure with a threefold symmetry, and showed that in the frequency range considered, two HOMs (TM011 and TE111) remain trapped. Finally, we studied methods to detrap these modes.

3-FOLD SYMMETRY CAVITY

The AC cavity shown in Figure 1 has a radius (r) of 3.0 cm and a height of 3.5 cm. The cylindrical cavity is coupled to three square waveguides, 120° apart, each having a width of 3.5 cm. We calculated the frequencies of
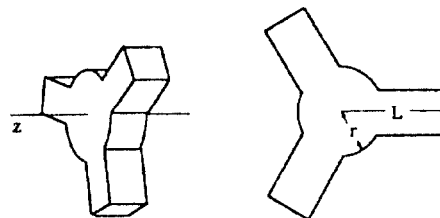

Fig. 1 A threefold symmetry cavity (ref. 6)

the TM and TE modes of this structure with URMEL-T for waveguide lengths (L) of 7.3, 7.9, 8.5, 9.1 and 18.0 cm. For ease of mode identification, only half of the structure was

modeled with reflection symmetry imposed on the half plane. A 32000-point mesh is used for the half model with the longest guide length. The number of mesh points for shorter guide lengths was reduced to maintain compatible mesh fineness. The beam pipe was not included in the 2-D model as its effect on the external Q was judged to be negligible. Table 1 lists the frequencies of the TM modes, with principal electric fields along the axis of the resonator, shorted at various guide lengths:

Table 1 Modal frequencies vs guide lengths for AC cavity

| Mode	7.3 cm	7.9 cm	8.5 cm	9.1 cm	18.0 cm
TM010	3354.30	3360.94	3352.05	3356.40	3341.75
TM110	4637.98	4603.07	4556.38	4526.22	4335.70
TM020	5104.74	4989.96	4865.69	4785.28	4376.92
TM120	5699.26	5529.12	5374.89	5252.20	4553.26
TM030	6682.62	6367.92	6101.79	5883.56	4664.38
TM130	6955.29	6730.32	6498.38	6292.62	4893.36
TM210	7956.85	7683.32	7448.07	7255.65	
TM040	8371.52	7927.96	7545.96	7203.79	5101.62
TM140				8161.31	5340.50
TM050				8542.02	5640.47
TM150					5865.92
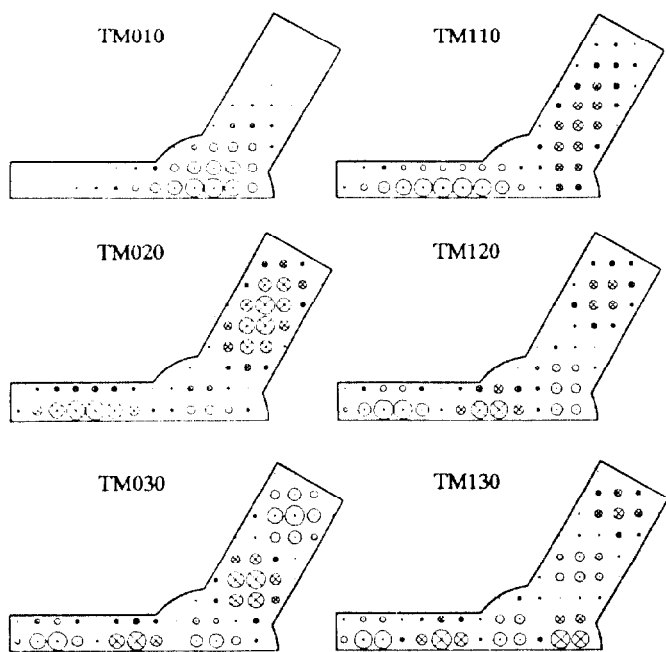
Fig. 2 Electric field plots from URMELT-T

A typical set of axial electric field plots is shown in Figure 2 for the L=9.1 cm case. The phase shifts, defined as:

$$\varphi = \frac{L_g}{c} \sqrt{\omega^2 - \omega_c^2} + m\pi$$

are plotted in Figure 3 for both the monopole (TM0n) and dipole (TM1n) modes as a function of frequency. In the above expression, ω is the angular frequency for a given mode, ω_c is the waveguide cutoff, L_g is equal to L-r, and c is the speed of light. The integer m depends upon the branch on which the mode appears. When properly chosen all the points for a specific symmetry fall on a single curve. This is illustrated in Figure 3, which includes all data from four guide lengths (excluding the longest length). The phase shifts for the monopole modes (represented by data points on the upper curve) undergo a change less than π in the frequency range considered. The data were fitted to a single-resonance 4-point formula[2] with a frequency of 9309 MHz and a Q of 2.3. The data for the dipole modes (lower curve) clearly show that there are two resonances in the same frequency range. The phase shifts in this frequency range undergo a change of 2π. The lower curve on Figure 3 is a theoretical fit obtained with a two-resonance formula[2] for the phase shifts:

$$\varphi(\omega) = \tan^{-1}\left(\frac{v_1}{\omega - u_1}\right) + \tan^{-1}\left(\frac{v_2}{\omega - u_2}\right) - \chi(\omega) + m\pi$$

$$\chi(\omega) \approx \chi_0 + \chi_1 \omega$$

The resonance frequencies of 4459 MHz and 7350 Mhz, and their corresponding Q of 2.7 and 6.3 were obtained from the six parameters u_1, u_2, v_1, v_2, χ_0 and χ_1 fitted to the data. A high degree of consistency for these results is evident by selecting data points from different crossed branches. We also used the data points from a *single* run with the longest guide length to calculate the dipole resonance frequency and Q. We obtained, using the four-point formula of reference 2, a resonance at 4311 MHz with Q=2.6, or 4385 MHz with Q=2.9, depending on the selection of the four points. These were consistent with the results for the lower resonance obtained from Figure 3 using data from four different runs. Data for the monopole modes using only the longest guide length were insufficient to yield a four-point solution. The extremely low Q values for the single monopole and two dipole resonances lead us to conclude that principal TM mode resonances in the AC cavity are indeed highly damped.
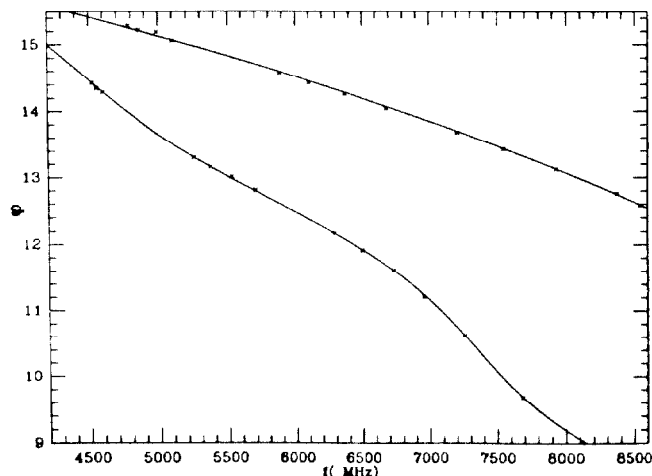

Fig. 3 Phase shift vs frequency Plot

TRAPPED MODES AND DETRAPPING

A review of the AC cavity URMEL-T plots of the electric fields in the plane perpendicular to the axis of the resonator shows that there are two possible trapped modes. These are shown in Figure 4, identified as (a) a TE111 mode, and (b) a TM011 mode in the cavity. To assess possible impact of these trapped modes on the accelerating cavity, we considered a π-mode, X-band accelerating structure with a threefold waveguide symmetry, similar to the AC cavity, using 3-D MAFIA models with up to 460000 mesh points. The 3-D models included long waveguide lengths (up to five times the cavity radius) and a finite cavity and waveguide height ($\approx\lambda$, where λ is the fundamental wavelength). The waveguide width was chosen so that the cutoff frequency is above the fundamental and below the HOM. The MAFIA models confirm that the TE111 and TM011 modes are in fact trapped in the cavity. The TE111 mode may not require damping because its impedance arises only from the probably very small TM contamination. On the other hand, damping is required for the TM011 mode. In order to minimize emittance growth of electron bunches over a very long distance, as in a linear collider, it was desirable to eliminate as much strayed
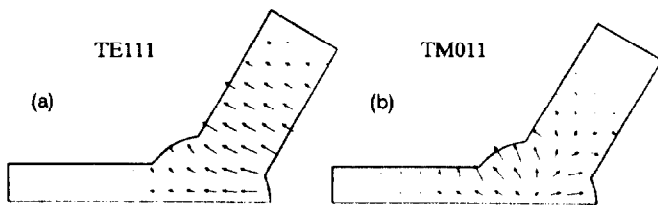

Fig. 4 Trapped modes in the AC cavity

fields in the structure as possible. We therefore considered methods to detrap the TE111 and TM011 modes. In a first unsuccessful attempt we tried to shift each of the three waveguides by a small offset (about 1/10 of the cavity height) with respect to the cavity along the beam direction. This proved insufficient to detrap the modes. In a second attempt, we tried to break the symmetry of the waveguide with respect to the cavity by reducing half of its height. This detrapped the TM011 mode (though not the TE111 mode), but it also distorted the accelerating mode[7]. In a third attempt we increased the waveguide height by 50% in an unsymmetrical way with respect to the cavity. The results of this calculation are shown in Figures 5a and 5b, showing two views of the detrapped TE111 and the TM011 mode, respectively. By making two MAFIA runs at different guide lengths, we were able to use the derivative method[3] to calculate the loaded Q. The TE111 mode is effectively detrapped with a Q of 10.9. The Q of the TM011 mode is substantially reduced, but still over 100. Oversized waveguides preclude installation on adjoining cavities. But damping waveguides may not be needed in every cavity if they are used in combination with other methods[8] of wakefield suppression.
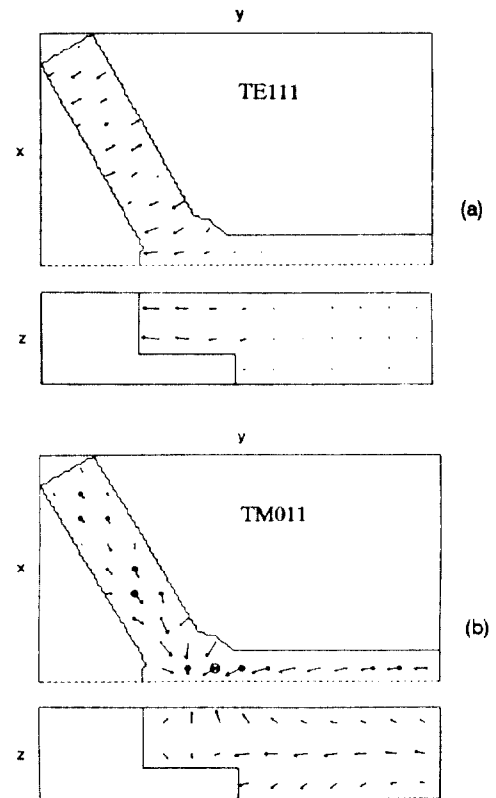

Fig. 5 Detrapped TE111 and TM011 modes

CONCLUSIONS

The problems of trapped modes which have persisted in previous damped structure designs have been partially solved with a threefold symmetry. Some progress has been made in detrapping the newly found trapped TM011 and TE111 modes unique to this geometry.

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