

Determination of Field Strength and Quality Factor of Heavily HOM Damped Accelerator Cavities*

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Abstract

Two methods of measuring field strength in accelerator cavities, heavily damped with respect to higher order modes (HOM), are presented. From the results of the field measurements the coupling (damping) factor and thus the quality factor of the damped resonator can be derived. Measurements on a pillbox resonator with heavily damped TM_{110} -mode ($Q < 20$) demonstrate the usefulness of the techniques presented, even in this extreme range.

1. INTRODUCTION

For use in future linear colliders, iris structures are proposed, operating at S-, X-, or K-band. In all these frequency ranges, especially at X- and K-band, wake field effects play an important role [1, 2]. They are mainly due to HEM_{11} -modes. To reduce beam perturbing influence slotted irises or wall-slits are well suited to couple those modes into loads [3, 4]. Shape, orientation and number of slots remain subject to investigation. Up to now the effectiveness of such a damping system was judged by measurement of external Q based upon the Slater-method [4]. However, this technique turns out to become impractical for cases where the number of waveguides attached to the structure exceeds two. Neither the 3dB technique will be precise enough to meet requirements, especially in cases where mode overlap occurs.

Because only the effect of the fields on the particles is of interest we looked for ways to determine them directly. Two methods seem to be appropriate. One is based on measurement of field strength using two antennas. The other is the application of nonresonant perturbation theory [6].

2. THEORY

2.1 Antenna Method

We consider a microwave source MS delivering the power P_{inc} at a fixed frequency ω to the input port EA of the resonator. At the input port a certain amount of power P_r will be reflected. Only P_i will enter the cavity (see Fig. 1). The field at the weakly coupled output antenna AA is proportional to $\sqrt{P_o}$. When the mode damper is attached, P_{ext} is extracted from the cavity.

To allow for a measurement of the intrinsic properties of the undamped cavity the damper is detached and the coupling hole is closed by a short. P_{iu} entering the resonator

is proportional to the square of the electric field and proportional to P_{ou} , u denoting the undamped case.

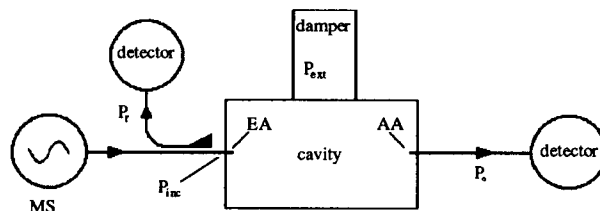


Fig. 1. Experimental setup for the antenna method

Adjusting the output power of the source such that P_i is kept constant in the damped (index d) and the undamped case we find

$$\frac{E_u^2}{E_d^2} = \frac{P_{iu}}{P_{iu} - P_{ext}} = \frac{P_{vd} + P_{ext}}{P_{vd}} = \frac{P_{ou}}{P_{od}} = 1 + K \quad (1)$$

under the condition that the mode geometry remains unchanged. K is the coupling coefficient which is defined by the ratio of power delivered to the damper P_{ext} and the power P_{vd} dissipated in the cavity. In practice the ratio of P_{ou}/P_{od} is not very easy to measure especially for a K in the order of 500, because of the weak coupling of the output antenna and the very low field levels at this point.

Therefore the measuring procedure [7] is as follows:

Starting with the coupling hole closed the power levels P_{iu} and P_{ou} are determined. Thereafter the damper is attached and the output of the source is increased until P_{od} equals P_{ou} ; the fields are then equal. This means that the input power has been increased $K+1$ times. $K+1$ can easily be measured as

$$\frac{\Delta P_i}{P_{iu}} + 1 = \frac{P_{ext}}{P_{vd}} + 1 = \frac{E_u^2}{E_d^2} = K + 1 \quad (2)$$

giving the ratio of the field strength in the undamped and the damped case. The coupling (damping) coefficient also links the values Q_0 of the undamped and Q_L of the damped structure again under the premise that the field distribution of the mode remains unchanged by the damping system:

$$Q_L = \frac{Q_0}{1 + K} = Q_0 \frac{E_d^2}{E_u^2} \quad (3)$$

2.2 Nonresonant Perturbation Theory

The nonresonant perturbation technique allows the measurement of fields both electric and magnetic in an arbitrary cavity by observing the change of the complex reflection coefficient Γ at the input port while a bead is

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pulled through the structure [6,8]. No resonance is required. If the bead consists of isotropic material we find

$$2P_{inc}(\Gamma_p - \Gamma_n) = 2P_{inc}\Delta\Gamma = -i\omega(\epsilon_0\alpha_e\vec{E}_n^2 - \mu_0\alpha_m\vec{H}_n^2) \quad (4)$$

where p denotes the perturbed case, n the non-perturbed case, and α depends on the shape and material of the bead. Since we are only interested in the electric field, we obtain

$$\vec{E}_n^2 = \frac{2P_{inc}\Delta\Gamma}{i\omega\epsilon_0\alpha_e} \quad (5)$$

using a dielectric bead. We get the shuntimpedance from

$$R_s = \frac{2\left\{\int_0^L \sqrt{|\Delta\Gamma|^2} dz\right\}^2}{\omega\epsilon_0\alpha_e(1-|\Gamma_n|^2)} \quad (6)$$

One can now apply (1). Because we only want to know the ratio of the fields it is not necessary to know α_e :

$$\frac{E_u^2}{E_d^2} = \frac{\omega_d|\Delta\Gamma_u|}{\omega_u|\Delta\Gamma_d|} \quad (7)$$

Furthermore it is not necessary to know $K+1$ for every point along a path parallel to the beam axis but only a mean value of E . In this case a dielectric rod, integrating the field over the length of the cell, can be used. To find ω_d the frequency region of interest has to be scanned for the highest value of $|\Delta\Gamma_d|$.

Depending on the value of Q_0 of the undamped cavity it is sometimes necessary to measure the field strength resp. the shuntimpedance with the well known resonant method because the rod will cause a frequency shift too large to apply the nonresonant technique. Instead of (7) one may use

$$\frac{E_u^2}{E_d^2} = \frac{\omega_d Q_0 (1-|\Gamma_u|^2) \frac{f_0^2 - f^2}{f^2}}{2\omega_u |\Gamma_d|^2} \quad (8)$$

Herein f_0 and f denote the resonances before and after inserting the bead.

2.3 Transversal Shuntimpedance

A particle traversing a dipole type cavity field (say) off the beam axis will experience a deflecting force. The transversal momentum gain can be expressed as [5]

$$\Delta\vec{p}_y = i\frac{q}{kc} \int_0^L \left(\frac{\partial E_z}{\partial y}\right)_{y=0} dz \vec{e}_y \quad (9)$$

Taking into account the energy dissipated in the accelerator one finds the definition of the transversal shuntimpedance per unit length

$$r_{\perp} = \frac{\left[\frac{1}{k}\left(\frac{\partial E_z}{\partial y}\right)\right]^2}{dP/dz} \quad (10)$$

r_{\perp} can be obtained from the longitudinal shuntimpedance r taken at an off axis position where $\omega y = c$.

4. EXPERIMENTAL RESULTS

To show the applicability of the methods described above in the range of $Q < 20$ a pillbox resonator has been built. In order to damp the TM_{110} -mode the cavity walls are slotted (see Fig. 2)

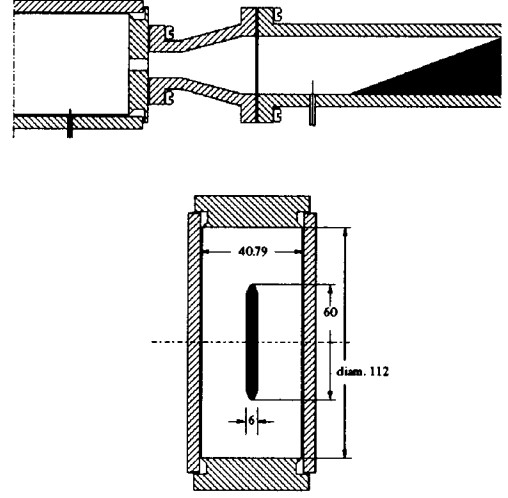


Fig. 2. Pillbox cavity with damping system

The cavity is made of brass ($\sigma = 1.46 \cdot 10^7 \Omega^{-1}m^{-1}$). The waveguides and the matching sections consist of aluminum. Their cutoff is at 2.498 GHz. This is well above the theoretical value for the fundamental mode of the pillbox (2.049 GHz).

All data presented in the following refer to measurements done with rods. Since antenna results are almost identical they are not presented here.

First the coupling slots were closed and the properties of the undamped cavity were measured, especially the transversal shuntimpedance R_{\perp} of the TM_{110} -mode. Measurements were done with a dielectric rod of 0.5 mm diameter.

Table 1.

Results for the TM_{110} -mode				
	f_0 [GHz]	Q_0	R_{\perp} [k Ω]	r_{\perp}/Q [k Ω/m]
theory	3.27	10245	691	1.65
exp.	3.23	6410	424	1.62

As can be seen the measurements show good agreement with theoretical values. For the transversal shuntimpedance per unit length we get

$$r_{\perp} = 10.4 \frac{M\Omega}{m} \quad (11)$$

After attaching the damping system the measurements were repeated. The diameter of the rod had to be increased to 2mm since the field strength had decreased strongly. A relatively thick rod has, of course, less resolution for position information. Another point of interest is the choice of coupling position and kind. An antenna located at one of the waveguides proved to be the best decision since it can be

made large enough to provide high field levels but does not perturb the field geometry of the mode (Fig. 2).

In Fig. 3 a comparison between direct coupling to the cavity (15mm antenna length) and coupling to one of the waveguides is given (see also Table 2).

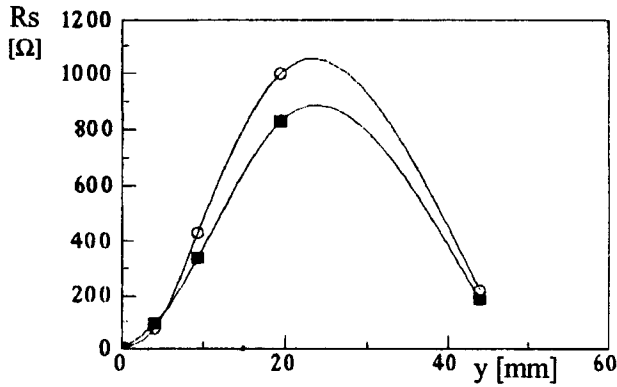


Fig. 3. Comparison between data measured with direct coupling to the cavity (circles) and coupling to a waveguide (filled square).

Table 2.

Shuntimpedance R_s for several off axis positions

y-position [mm]	R_s [Ω] (direct)	R_s [Ω] (waveg.)
4.1	73	91
9.2	430	339
19.3	1000	830
44	220	184

From these results one now can derive a transversal shuntimpedance per unit length of

$$r_{\perp} = 19.1 \frac{\text{k}\Omega}{\text{m}} \quad (12)$$

leading to a damping factor combining (11) and (12) of

$$\frac{r_{\perp}}{\Gamma_{\text{Ld}}} = \frac{10.4 \text{M}\Omega/\text{m}}{19.1 \text{k}\Omega/\text{m}} \approx 550 \quad (13)$$

which is identical to E_u^2/E_d^2 since $r_{\perp} \propto E^2$.

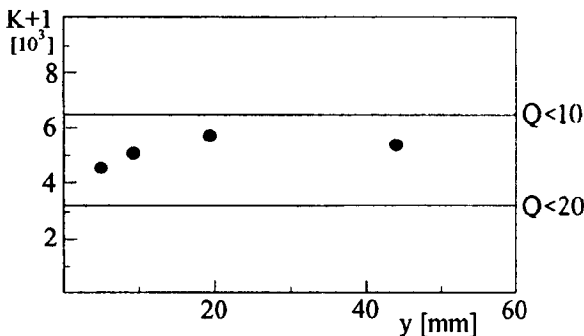


Fig.4. Damping factor against off axis position

In Fig. 4 the damping factor is drawn against the off axis position. The highest value corresponds to a Q of 11, the lowest to a Q of 14, indicating the influence of the coupling system on the field geometry.

The results were then compared to measurements of Q using Slater's method (see Fig. 5) [4]. The mean value for several measurements appeared to be $Q=9$.

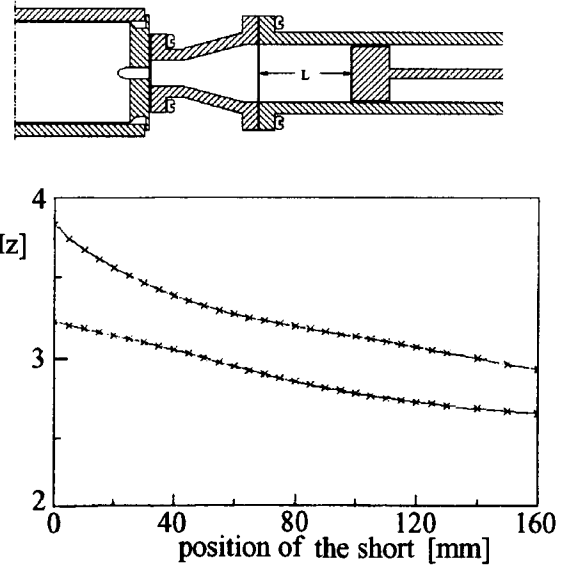


Fig. 5. Measurement setup and results for the Slater measurement. The frequency shift is plotted against the position L of the short. The upper curve represents the waveguide resonance, the lower the cavity resonance.

4. DISCUSSION

For off axis positions near the maximum of the field both antenna and perturbation method gave nearly identical results. Due to the limited dynamic range of our source near axis results obtained with the antenna method become less accurate, but a more powerful source will cure the problem. All results differ only in a range of 5%. Comparing our results it should be mentioned that the Q values obtained with the Slater technique tend to be too low since all losses are assumed to occur inside the coupling system rather than in the resonator. From this point of view the agreement between the different techniques is very good.

5. REFERENCES

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