EXPERIMENTAL DETERMINATION OF FIELD STRENGTH AND QUALITY FACTOR OF HEAVILY DAMPED ACCELERATOR CAVITIES

Indexing terms: Measurement, Electromagnetic fields, Q-factors

Two methods of measuring field strength in accelerator cavities, heavily damped with respect to higher order modes, are presented. From the results quality factors can be derived. First measurements have been carried out on cavities for future linear colliders. Results are presented.

Introduction: For use in future linear colliders, iris structures are proposed, operating at X to K band. Owing to these high frequencies, wake effects will play an important role.[1,2] To remove beam perturbing higher order modes, slotted irises are well suited to couple those modes into a load.[3,4] Shape, orientation and number of coupling slots remain subject to investigation. According to the Panofsky theorem[5,6] TM-type dipole and quadrupole modes prove harmful to the beam. Thus far the effectiveness of damping systems has been judged by measuring Q values[4] of the damped cavity. However, a Q of about 10 cannot be measured precisely with the 3 dB method, and measurements using the Slater formula[7] are not possible when mode overlap occurs. Field measurements with the resonant bead pull method, which needs knowledge of Q, are therefore nearly impossible.

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

Antenna method: We consider a microwave source delivering the power P_{inc} at fixed frequency ω to the input port of the resonator. At the input port a certain amount of power P_r will be reflected. Only P_i will enter the cavity (Fig. 1). The field at the output port is proportional to $\sqrt{(P_0)}$. When the mode damper is attached, P_{ext} is extracted from the cavity.

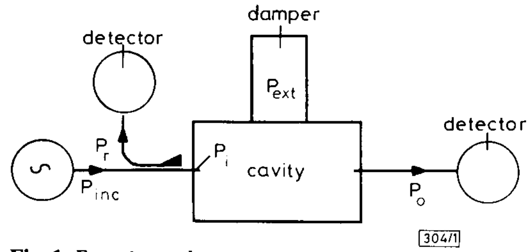

Fig. 1 *Experimental setup*

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_i entering the resonator is proportional to the square of the electric field and proportional to P_0. Adjusting the output power of the source such that P_i is kept constant in the damped (index g) and undamped (index u) cases we find

$$\frac{E_g^2}{E_u^2} = \frac{1}{1+K} = \frac{P_0^g}{P_0^u} \tag{1}$$

K is the coupling coefficient which is defined by the ratio of power delivered to the damper P_{ext} and the power P_l dissipated in the resonator.

The measuring procedure is as follows. Starting with the coupling hole closed the power levels P_i and P_0 are measured. Thereafter, the damper is attached and the output of the source is increased until P_0^g equals P_0^u; the fields are then equal. This means that the input power has been increased $K + 1$ times. $K + 1$ can easily be measured as

$$\frac{KP_i}{P_i} + 1 = K + 1 = \frac{E_u^2}{E_g^2} \tag{2}$$

and gives the ratio of the field strength in the undamped and damped case. The coupling coefficient also links the values Q_0 and Q_L of the damped structure under the premise that the fields remain unchanged.

$$Q_L = \frac{Q_0}{1+K} = Q_0 \frac{E_g^2}{E_u^2} \tag{3}$$

Nonresonant perturbation method: Nonresonant perturbation techniques allow for measurement of fields both electric and magnetic in an arbitrary cavity by observing the change of the complex reflection coefficient ρ at the input port while a bead is pulled through the structure.[8,*] No resonance is required. If the bead is assumed to be made of isotropic material we find

$$2P_{inc}(\rho_p - \rho_n) = -i\omega(\varepsilon_0 \alpha_e \vec{E}_n^2 - \mu_0 \alpha_m \vec{H}_n^2) \tag{4}$$

where p denotes the perturbed case, n the unperturbed case, and α depends on the shape and material of the bead.[9] Because we are only interested in measuring electric fields we obtain

$$\vec{E}_n^2 = \frac{2P_{inc}\,\Delta\rho}{i\omega\varepsilon_0\alpha_e} \qquad \Delta\rho = (\rho_p - \rho_n) \tag{5}$$

We can now instantly apply eqns. 1 and 2. Because we are only interested in the ratio of the fields it is not necessary to know α_e.

$$\frac{\vec{E}_u^2}{\vec{E}_g^2} = \frac{\omega_g\,\Delta\rho_u}{\omega_u\,\Delta\rho_g} = 1 + K \tag{6}$$

Furthermore we do not need to know $K + 1$ for every point along the beam axis but only the mean value of $\vec{E}$. In this case

* HERMINGHAUS, H.: Private communication

a dielectric rod, integrating the field over the length of the cell, can be used. To find ω_g the frequency region of interest has to be scanned for the highest value of $\Delta\rho_g$.

Experimental results: A two-cell iris structure was chosen as a test cavity to reduce mode overlap. With its parameters, a multicell cavity would have a frequency of 2·45 GHz for the TM_{010}–$2\pi/3$-acceleration mode. The TM_{110}–π-mode (Fig. 2), the most dangerous mode, was in the range of 3·5 GHz. First we used a single slot coupling system (Fig. 3). The fields can be expected to become strongly asymmetric as the slot height is increased (varying from 2–15 mm by exchange of the iris). In our case the lowest Qs are high enough to allow comparison with 3 dB measurements. At the waveguide port a rectangular waveguide (60 mm width, 20 mm height) was attached and terminated by a load. The mode couples inductively to the waveguide exciting a TE_{10} mode. We have used two antennas (antenna method) which could be placed at several positions as indicated in Fig. 3. Further, a dielectric stick (1·5 mm diameter) could be inserted at the same positions (nonresonant method). The results obtained with both methods agreed within $<5\%$. Therefore the following Figures show only the results for one method. Fig. 4 shows the interdependence between damping factor and slot height for three off axis positions.

We see that:

(i) The field distribution is influenced by the unsymmetric damping system.

(ii) The closer to the axis the stronger is the decrease of field strength with slot height (Fig. 4).

(iii) The wider the slot the stronger is the change of field distribution (Fig. 5).

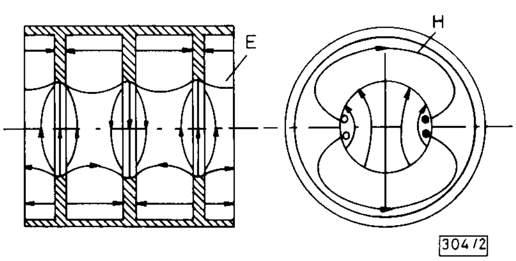

Fig. 2 *TM_{110}–Π-mode, E- and H-field plot*

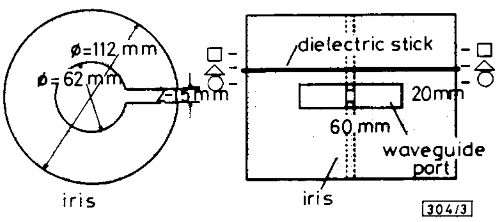

Fig. 3 *Coupling slot geometry for two-cell structure*

□, △, ○ position of antennas

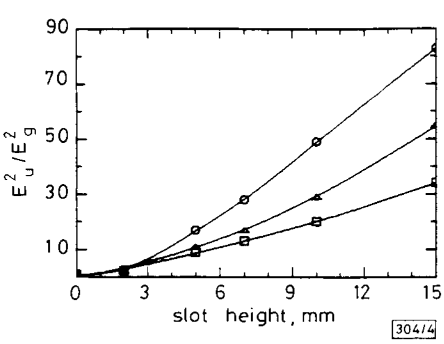

Fig. 4 *Damping factor against slot height*

Off-axis position

○ 4·35 mm

△ 10·95 mm

□ 21·05 mm

(iv) Where field distribution has not changed, the results obtained by the antenna method or nonresonant method equal those obtained by 3 dB measurements (Fig. 6, 21·05 mm offset).

Secondly, a two slot coupling system, which is symmetric in contrast to the single slot system (Fig. 7), was tested (Fig. 8). The damping was approximately doubled. It appears that in

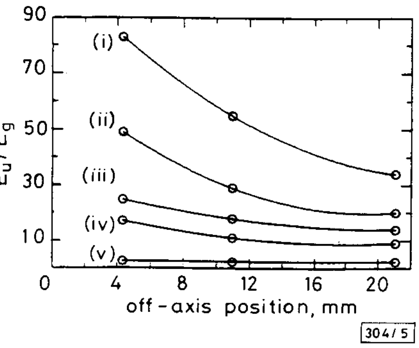

Fig. 5 *Damping factor against off-axis position*

(i) 15
(ii) 10
(iii) 7
(iv) 5
(v) 2

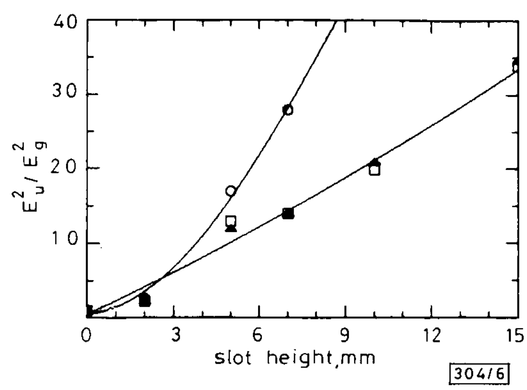

Fig. 6 *Comparison of antenna method and 3 dB method for single slot*

○ 4·35 mm off axis

□ 21·05 mm off axis

▲ 3 dB method

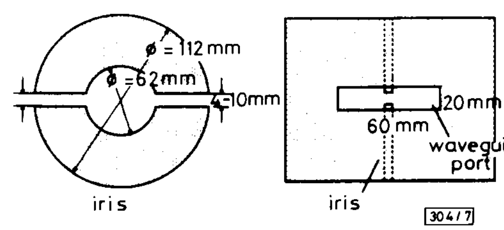

Fig. 7 *Two slot coupling system*

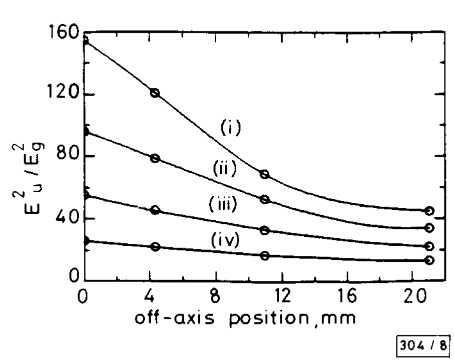

Fig. 8 *Damping factor against off-axis position*

Slot height (mm)

(i) 10
(ii) 8
(iii) 6
(iv) 4

this case the field distribution remains unchanged near to the axis. We found good agreement between Q and field measurements (Q measured applying the Slater formula[7] as the 3 dB method was no longer precise enough).

Discussion: The experiments have shown that the effectiveness of a strong damping system can be determined by the field strength nearby the axis. The two proposed nonresonant techniques are very well suited to the problem. These methods are also applicable when the resonant methods for Q measurements fail (very small Q, mode overlap, change of field distribution due to the damping system). For example the application of the 3 dB method on the single slot system (15 mm slot) gives a $K + 1$ of 36 ($Q_L = 230$, $Q_0 = 8200$, $K + 1 = Q_0/Q_L$), whereas the antenna method or the nonresonant perturbation method gives values of $K + 1$ depending on the off-axis position (e.g. $K + 1 = 83$ for an offset of 4·35 mm).

For the symmetric two slot system the maximum damping factors obtained by antenna and nonresonant perturbation measurements on-axis corresponded to the value obtained by direct measurement of Q. For example Q_L was measured to be 37 for a 10 mm slot with $Q_0 = 5700$, $K + 1 = 154$. This is in good agreement with the result of Fig. 8 (upper curve on the axis).

The two discussed nonresonant methods allowed fast and correct measurements for the examples presented, and seem to be useful for the investigation of accelerator structures in general.

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References

1 BANE, K., and SANDS, M.: 'Wakefields of very short bunches in an accelerating cavity', *Particle accelerator*, 1990, **25**, pp. 73–95
2 SCHNELL, W.: 'The study of a CERN linear collider, CLIC'. CERN-LEP-RF/88-48, October 1988
3 PALMER, R. B.: 'Dampled acceleration cavities'. SLAC-PUB-4542, 1988
4 DERUYTER, H., *et al.*: 'Damped accelerator structures'. SLAC-PUB-5263
5 PANOFSKY, W. K. H., and WENZEL, W. A.: 'Some considerations concerning the transverse deflection of charged particles in radio–frequency fields', *Rev. Sci. Instrum.*, 1956, **27**, p. 967
6 HÜLSMANN, P., and KURZ, M.: Internal Report 90-20, Institut f. Angew. Physik, Frankfurt, 1990
7 MAIER, L. C., and SLATER, J. C.: 'Field strength measurements in resonant cavities', *J. Appl. Phys.*, 1952, **23**, (1), p. 85
8 STEELE, C. W.: 'A nonresonant perturbation theory', *IEEE Trans., Theory and Technology*, 1966, **MTT-14**, (2), pp. 70–74
9 SLATER, J. C.: 'Microwave electronics' (D. Van Nostrand Company, Inc., New York, 1050), pp. 68–77