DAMPING OF HIGHER-ORDER MODES IN ELECTRON LINACS*

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Abstract

Future linear e^+-e^-- colliders will operate at frequencies up to ten times higher than existing machines (e.g. CLIC [1] is being designed for 30GHz operating frequency). Therefore beam induced effects like long range - and short range wakes cannot be neglected. They are capable of severely deteriorating beam quality. The most dangerous modes existing in an iris structure will be evaluated and it will be shown to which extent they can be suppressed. Experimental work has been done determining low Q-values using a simple and precise measurement technique. First results will be presented.

Introduction

Existing electron linacs (e.g. SLAC, LIL) operating at S-band frequencies are scarcely affected by wake-effects. As the wake-potentials scale with ω^2 for longitudinal wakes and with ω^3 for transversal wakes their influence on the beam has to be taken into account for future colliders [2].

All proposed e^--linacs are for colliders are iris structures. To get rid of beam perturbing higher order modes slotted irises have proved to be an effective method of coupling those modes into a load [3].

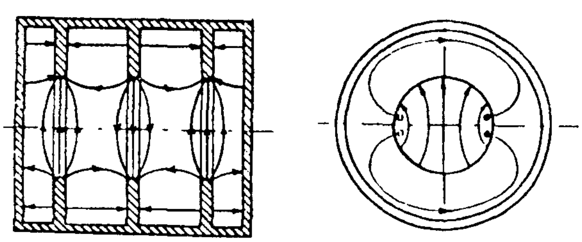

Fig. 1 TM_{110} π-mode, E- and H- field plot

Shape, orientation and number of coupling slots remain subject of investigations. According to Panofsky's theoreme [4, 7] TM-type dipole and quadrupole modes prove to be harmful to the beam. Therefore the TM_{110} π-mode is of special interest due to its phase velocity close to the one of the accelerating mode (see Fig. 1).

To judge the effectiveness of the coupling slots, the coupling factors for the perturbing modes have to be measured. To do this, Chipman's method (measuring the reflection coefficient of a complex load using a resonant line) [5] was used.

Experimental setup

In the experiments a three-cell iris structure ($2\pi/3$-mode TM_{010} at 2.45 GHz tuned to $v_{ph}=c$) was used. The middle iris of the structure was slotted and a rectangular waveguide (60mm width, 20mm height) was attached and terminated by a load. For the measurement of the coupling factors the load was replaced by a sliding short (see Fig. 2).

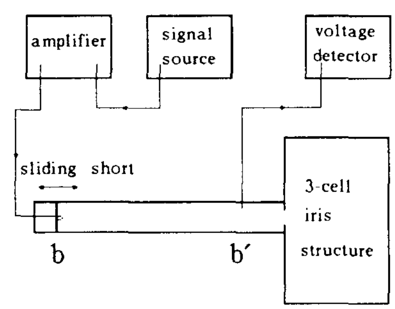

Fig. 2 Measurement setup

The rf-signal was fed from the signal source into a microwave amplifier and then inductively coupled to the waveguide exciting a TE_{10} wave. The amplitude of the rf in the waveguide was observed using a voltage detector.

The coupling slot to the waveguide was of 10mm height and 60mm width, the slot height in the iris varied from 1mm to 10mm (see Fig. 3).

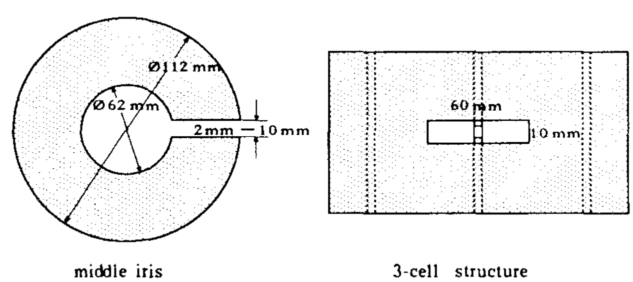

Fig.3 Coupling slot geometry

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Theoretical aspects of the measuring method

We consider the signal-flow plot (sfp) of a transmission line terminated with a short on one side and with the attached cavity on the other, the cavity itself being represented by the reflection coefficient ρ_l. b and b′ are complex wave amplitudes (see Fig. 4).

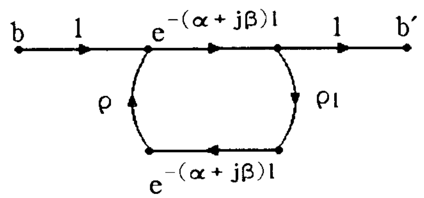

Fig. 4 Signal flow plot of the experimental setup $(\alpha + j\beta)$ = propagation constant of the line

It can be shown that the measured signal is proportional to the magnitude of the transmission factor $t_{bb'} = b'/b$. Hence we have to calculate $t_{bb'}$. Solving the sfp for $t_{bb'}$ we find

$$t_{bb'} = \frac{e^{-(\alpha + j\beta)l}}{1 - \rho\rho_l\, e^{-2(\alpha + j\beta)l}} \quad . \qquad (1)$$

The reflection coefficient ρ is chosen -1 (sliding short) and introducing $\Gamma = \rho\rho_l = \exp(-2(\sigma + j\varkappa))$ we finally get:

$$|t_{bb'}| = \left(2\sqrt{|\Gamma|}\,\{\sinh^2(\alpha l + \sigma) + \sin^2(\beta l + \varkappa)\}\right)^{-1} . \qquad (2)$$

At a certain $\beta l_0 + \varkappa = n\pi$, n being an integer, a maximum of the transmission factor will be observed. From this we get the phase information (modulo π).

The height of the maximum is proportional to the sinh term. To find σ, the line length l is varied by $\delta l_{1,2}$ to each side of the maximum until the signal has dropped to g times its value at l_0, $0<g<1$. We find from (2) that

$$\sinh\,(\alpha(l_0 + \delta l_1) + \sigma) + \sin\,(\beta(l_0 + \delta l_1) + \varkappa) = \sinh^2(\alpha l_0 + \sigma)/g\ , \qquad (3)$$

$$\sinh^2(\alpha(l_0 - \delta l_2) + \sigma) + \sin^2(\beta(l_0 - \delta l_2) + \varkappa) = \sinh^2(\alpha l_0 + \sigma)/g\ .$$

These equations now can be solved for σ. Often the damping coefficient α is very small in comparison with σ and can be neglected. In this case the two equations reduce to one. Now magnitude and phase of Γ are determined. If the sliding short cannot be thougt ideal one first has to measure its properties in order to get a correction for the value of ρ_l.

The coupling factors for the undercoupled and overcoupled case can be written as follows (at the minimum of ρ_l versus frequency):

$$k_u = \frac{1 - \rho_l}{1 + \rho_l}\ , \qquad k_o = \frac{1 + \rho_l}{1 - \rho_l} \qquad (4)$$

Which of these equations is applicable can be decided regarding the Smith chart affiliated with the problem.

Experimental results

For the purpose of identifying the eigenmodes of a resonator MAFIA [6] calculations for a three-cell iris structure were compared to perturbation ball measurements. The next neighbouring modes above the TM_{010} π-mode were identified and examined for their coupling properties [7] (see Fig. 1 and Fig. 5).

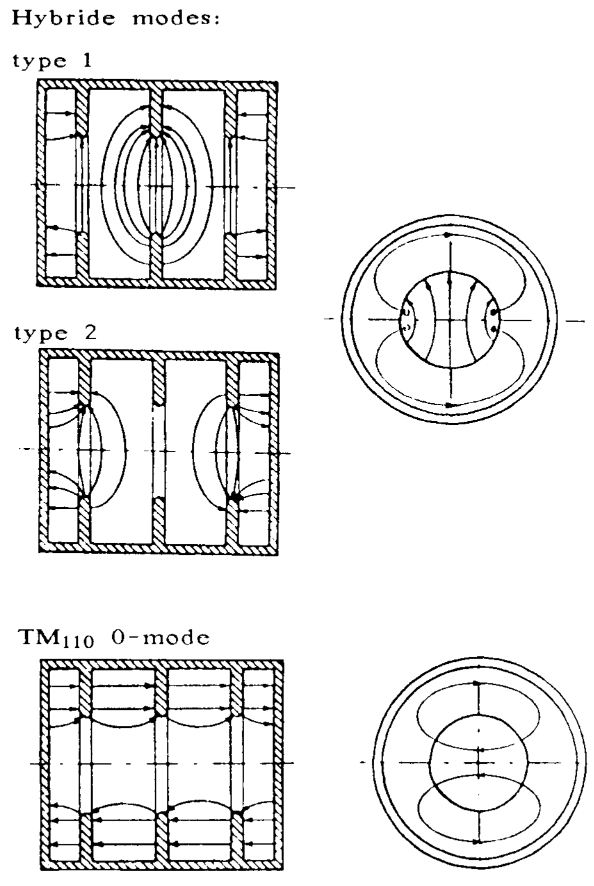

Fig. 5 Field plot of perturbing modes, E-field and H-field

The coupling factors of the modes to the waveguide were measured using slotted irises of various sizes.

Only one polarisation for each dipole mode would couple, the other is stongly suppressed by the slot. The following figures show reflection coefficients for several slot dimensions. All following figures refer to the TM_{110} π-mode.

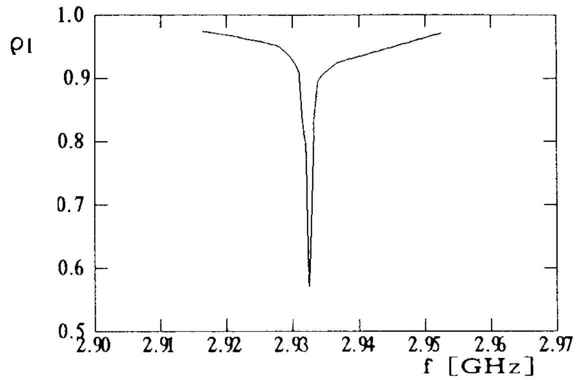

Fig. 6 Reflection coefficient versus frequency for a 5mm slot

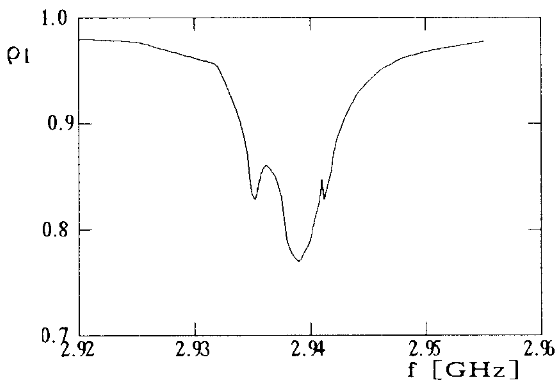

Fig. 7 Reflection coefficient versus frequency for a 2mm slot

The minimum left of the main minimum in Fig. 7 could be identified to be the second polarisation of the mode, the one to the right belongs to a resonance in the coupling system.

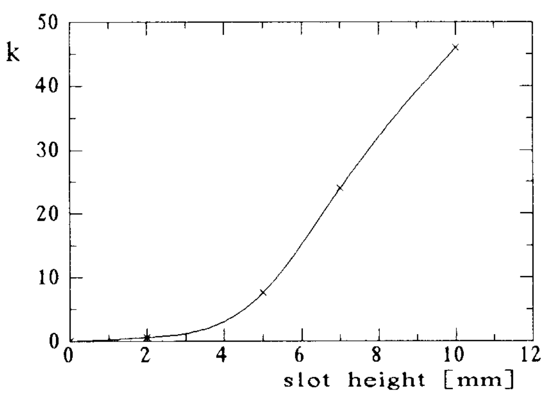

Fig. 8. Coupling factor versus slot height

The measurements were made with an uncalibrated sliding short, therefore all Q_l values are too high. This is true especially for the lowest values (assuming $\rho \approx -0.992$ corresponds to $Q_l \approx 70$ only for a 10mm slot).

Coupling coefficients were also measured for type 1 mode (see Fig. 5), results are given in Table I.

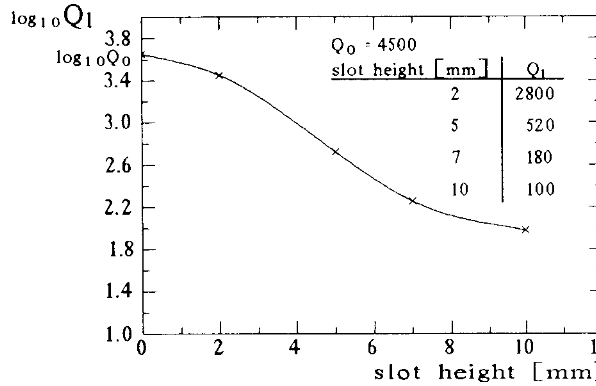

Fig. 9 Q_l versus slot height, $(Q_l = Q_0/(1+k))$

TABLE I
Coupling Factor k for Type 1 Mode
$Q_0 = 5000$

Slot height [mm]	k [1]
0	0.06
2	11
5	42

The TM_{110} 0-mode showed very weak coupling. Only for slots greater than 7mm slight coupling could be detected. The type 2 mode showed no coupling at all, due to the absence of fields in the middle iris. (see Fig. 5.).

Conclusions

Work on the structure described above has shown which amount of power of a certain mode (e.g. TM_{110} π-mode) can be brought out of a slotted iris structure. It could also be shown that the necessary low Q values of the disturbing modes can almost be achieved with one slot, a second slot should be sufficient. The problem of measuring very low Q values could be solved by using Chipman's method. This method does not require precise machining except for a calibration short.

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