Transversal Loss Factor of an rf-Focussing Iris Structure with Rectangular Holes*

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Abstract

By replacing the irises in an electron linac by a slit one gets a structure capable of focussing/defocussing an electron beam (rf-quadrupoles). Therefore one can think of a combination of rf- and conventional magnetic quadrupoles for transversal focussing in linear-colliders [1]. Furthermore they can meet the demands of BNS-damping without initial energy spread. Considering multibunch-operation of a collider, the long-range wake behaviour of this kind of structure has to be investigated. A three-cell structure has been built and investigated for dipole-type transversal long-range wakes. The experimental results are compared to numerical simulations done with MAFIA [2].

1. INTRODUCTION

Nearly all schemes proposed for future e^+-e^--linear-colliders are iris-type structures. Experiments will require luminosities in the range of $10^{33}\text{cm}^{-2}\text{sec}^{-1}$. Therefore it is of some advantage to accelerate a train of bunches rather than a single one on each rf-pulse, as it is possible to make better use of the available rf-energy.

The passage of the bunches leaves behind wake fields influencing subsequent bunches in the train. Transversal (dipole) wake fields lead to cumulative beam breakup instabilities which is extremely deleterious to a beam in a collider unless measures are taken to control this effect.

The spacing between adjacent bunches is several rf-wavelength. Since the transversal wakes continue to ring for a distance several times the bunch spacing, transversal bunch oscillations can grow very rapidly along the linac.

The focussing properties of the rectangular iris structure are described elsewhere [3]. In this paper we concentrate on the measurement of dipole loss factors by perturbation methods. A BBU criterion is applied to our experimental results to find out about the BBU behaviour of this kind of structure.

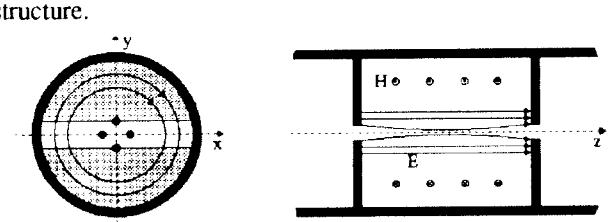

Fig. 1. rf-Quadrupole in TM_{010}–$\pi/2$-mode

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2. QUANTITIES RELATED TO BBU

2.1 Transversal loss factor and shuntimpedance

According to the Panofsky-Wenzel theorem [4] it holds that

$$\frac{\partial}{\partial s}\vec{W}_\perp = \nabla_\perp W \tag{1}$$

where W ($\vec{W}_\perp$) is the longitudinal (transversal) wake potential, s is the longitudinal coordinate in the bunch system. For a certain cavity mode W can be expressed in terms of the so called longitudinal loss factor k:

$$W(s) = 2k\cos\left(\frac{\omega}{c}s\right) \tag{2}$$

$$k = \frac{\omega}{4}\frac{R_s}{Q} \tag{3}$$

where R_s is the longitudinal shuntimpedance. One can see that k is only dependent the geometry of the cavity. Inserting (2) into (1) and solving for $\vec{W}_\perp$ one gets

$$\vec{W}_\perp = \vec{k}_\perp \sin\left(\frac{\omega}{c}s\right) \tag{4}$$

$$\vec{k}_\perp = \frac{\omega^2 y}{c}\frac{R_\perp}{Q}\vec{e}_y \tag{5}$$

where $k_\perp$, $R_\perp$ are the transversal loss factor and shunt-impedance, y is the off axis position.

$$R_\perp = \frac{c}{\omega y}R_s \tag{6}$$

$R_\perp$ is determined by taking the longitudinal R_s at an off axis position towards the maximum of the longitudinal electric field of the perturbing mode where $\omega y = c$ (choice of coordinates see Fig. 1).

2.2 Beam blowup criterion

For multibunch operation the wake field effects on the particles following in a train of bunches have to be minimized. Depending on the linac parameters this leads to required Q's of the deflecting mode of down to some 10, depending on the collider parameters. Then a bunch almost only experiences the wakes excited by the preceeding. Under these assumptions a handy criterion for beam stability can be derived. The so called daisy-chain model [5] gives

$$\left\{\frac{N(e\omega)^2}{m_0\gamma c^3}\left(\frac{r_\perp}{Q}\right)L_{eff}\right\} < 1 \tag{7}$$

Herein N denotes the bunch population, $r_\perp$ the transversal shuntimpedance per unit length, L_{eff} the effective accelerator length; $L_{eff} \approx 2L\sqrt{E_{init}/E_{final}}$. One possibility to reach the required Q for this kind of structure is to apply strong HOM damping [6].

3. EXPERIMENTS

3.1 Experimental setup

A three-cell structure was designed and tuned to v_{ph}=c in the TM_{010}-2π/3-mode at a frequency of 2.2 GHz. A sketch of the geometry is given in Fig. 2.

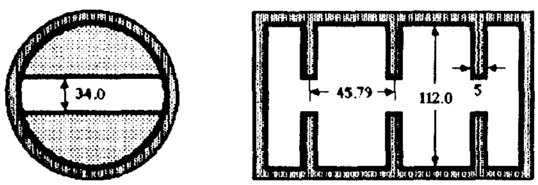

Fig. 2. Sketch of the geometry (dimensions in mm)

The transversal loss factor is derived from field distribution data obtained by different perturbation techniques. Therefore a computer-controlled test stand was used. Instead of moving the bead in our setup the cavity is moved for the reason of eliminating oscillations of the bead during the measurement process. For the same reason all components are mounted on a massive slab of granite. The supports on either side of the test bench are equipped with micrometers in order to allow for precise adjustment of the bead (see Fig. 3).

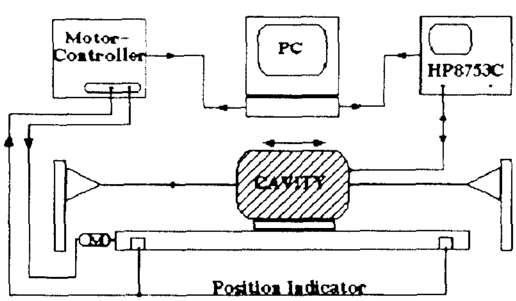

Fig. 3. Experimental setup

For measuring the fields thin dielectric and metallic needles (copper, 0.1 mm diameter, 8 mm length; Al_2O_3, 0.8 mm, 8 mm) and, additionally, a dielectric ball of 2 mm diameter were used. The setup could be changed to allow for replacing the thread by a dielectric rod of 0.8 mm diameter.

The used needles, balls, and rods can be described as rotational ellipsoids. The ratio between energy change in the cavity due to fields parallel and perpendicular to the symmetry axis of the bead, the so called selectivity, depends on ε and geometry.

The beads were calibrated in a TM_{010}-mode Pillbox cavity of well known geometry operating at 2.05 GHz.

3.2 Results

In order to measure the longitudinal component of the electric field in the TM_{110} - π-mode three different techniques were employed.

First a dielectric rod penetrating the entire cavity was inserted at several off axis positions. The diameter of the rod is small compared to its length, therefore its selectivity for the longitudinal component of the electric field can be assumed to be near the theoretical optimum of (ε + 1)/2 . Since there is no longitudinal on axis field for the examined mode any signal will be due to transversal field. Measuring off axis the transverse signal is subtracted and thus the shuntimpedance is determined. The error inherent to this

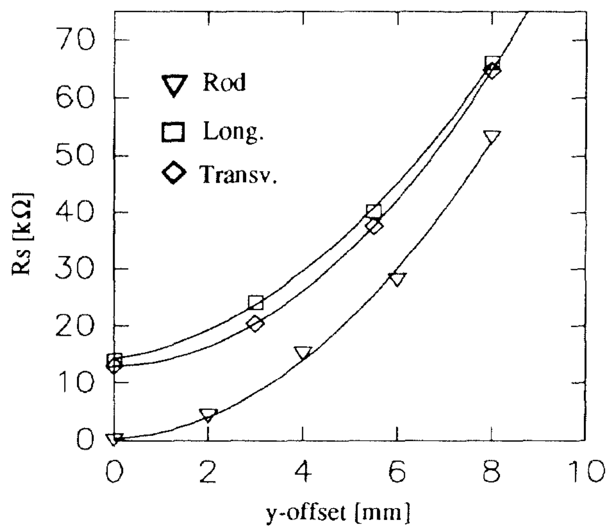

Fig. 4. Longitudinal shuntimpedance measured against y-off-axis position including transittime.

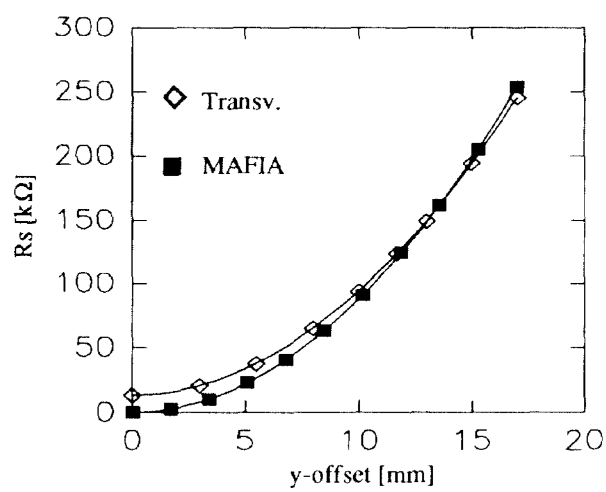

Fig. 5. Longitudinal shuntimpedance measured against y-off-axis position including transittime, MAFIA values weighted with Q_{exp}/Q_{num}.

technique will increase with off axis position because of violation of $\Delta E = 0$. But for a rough estimate this method seems to be acceptable (Fig. 4 , triangle).

In order to separate the longitudinal and transversal field components two subsequent measurements with beads of different ratio of length to diameter and thus different selectivity were performed. For best results the ratio of transversal and longitudinal selectivity should be as small as possible. The shuntimpedance was the determined by numerical integration of fields over the cavity length (Fig. 4, square).

At last the field was measured by moving a dielectric ball along the y-axis (perpendicular to the slit) in the mid-plane of one cell. Due to symmetry no transversal field components may there exist. The distribution of the longitudinal component along the z-axis was then measured with a uncalibrated bead at the appropriate y-offset. The bead was a piece of copper wire of length 8 mm and 0.05 mm diameter in order to guarantee for a good selectivity for the longitudinal electric field and little perturbation of the magnetic field. Both MAFIA and measurement found the distribution to be almost purely sinusoidal. Thus the shuntimpedance was obtained taking the measured field strength times the cavity length and a factor $2/\pi$ to the square. (Fig. 4, Fig. 5, diamond).

In Fig. 4 the results for the three experiments are presented. The curves for longitudinal and transversal measurement are close to each other within 10%. The offset on-axis is due to geometrical imperfections, the finite dimensions of the bead, and mainly due to the poor signal to noise ratio. In Fig. 5 shuntimpedances calculated by MAFIA weighted with the ratio Q_{exp}/Q_{num} are drawn against the results of the transversal measurement (filled square).

MAFIA values are obtained by integration of the E_z-component of the fields calculated with the frequency domain solver. Since these values already include transittime the experimental results had to be corrected for this in order to get comparable numbers. The transittime factor was found to be 0.67 (particle velocity equal c).

Table 1 gives an overview about the experimental and numerical data.

Table 1.

Comparison of results obtained by measurement including transittime and numerical simulation. * indicates results extrapolated by square fit, evaluated at $\omega y = c$.

	f_0 [GHz]	Q_0 10^3	$R_\perp$ [kΩ]	$\frac{R_\perp}{Q_0}$ [Ω]	$k_\perp[\frac{\Omega}{s}]10^{11}$
MAFIA	4.0715	14.77	148.9	10.08	2.579
Rod	4.0919	11.9	110 *	9.24	2.377
Transv.	"	"	123	10.34	2.657
Long.	"	"	135 *	11.35	2.917

Applying the experimental data and the parameters for a proposed 500 GeV S-band collider [7,8] to (7) we found a value of 0.1, the daisy-chain criterion is fulfilled for this example.

4. CONCLUSIONS

The transversal shuntimpedance and loss factor of the TM_{110}-π-mode were measured by three different perturbation techniques. The results were confirmed by numerical simulation. Presuming the Q values of the dipole mode can be lowered to numbers in the range of some 10, the daisy-chain-criterion is valid. Since it seems possible to reach this range [6], rf-focussing structures could be employed in a multibunch operation scheme in a linear collider.

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