THE MEASUREMENT OF TRANSVERSAL SHUNT IMPEDANCE OF RF DEFLECTOR

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Abstract

This paper presents the results of transverse shunt impedance measurement performed using field perturbation technique and comparison with numerical MWS simulations. The structure under test is the S-band 3-cell deflecting cavity, described in work [1]. The mentioned cavity operates with a dipole TM11-like mode with a phase shift of 120 deg per cell. The analyses were carried out with use of two types of perturbing beads: dielectric beads and metallic rings. The latter type perturbs the on-axis magnetic field much stronger than the electric field, which allows us calculating transversal shunt impedance using on-axis EM fields' values.

INTRODUCTION

The transverse potential in a deflecting cavity is given with the following equation:

$$V_{\perp} = \left| i\beta c\mu_0 \int H_{\perp}(z)\cdot e^{ikz/\beta}\cdot dz - \int E_{\perp}(z)\cdot e^{ikz/\beta}\cdot dz \right|, \quad (1)$$

where $H_{\perp}$ and $E_{\perp}$ are the values of on-axis transverse magnetic and electric strength magnitudes respectively. These values are to be measured in order to calculate the transverse shunt impedance per length given by:

$$r_{\perp} = \frac{V_{\perp}^2}{P_{\text{loss}}\, l}, \quad (2)$$

where P_{loss} is the power loss and l stands for the structure axis length.

The standard measurement technique [2] based on field perturbation and applied for our deflecting cavity will be described below.

Since a little bead is placed inside the rf cavity excited with a dipole mode, it will cause a resonant frequency shift Δf which equals to :

$$\frac{\Delta f(z)}{f_0} = \frac{1}{W}\left(k_H H_{\perp}^2(z) - k_E E_{\perp}^2(z)\right), \quad (3)$$

where W is energy stored in EM fields, k_H and k_E are magnetic and electric form-factors of the perturbing bead, f_0 is the eigenfrequency of unperturbed cavity and z is longitudinal coordinate of the bead. That means that one can measure the phase shift of transition coefficient $\Delta\angle S21$ with network analyzer at discrete positions of the bead and then calculate the frequency shift with the following expression [3]:

$$\frac{\Delta f}{f_0} = \frac{\Delta\angle S21}{2Q}, \quad (4)$$

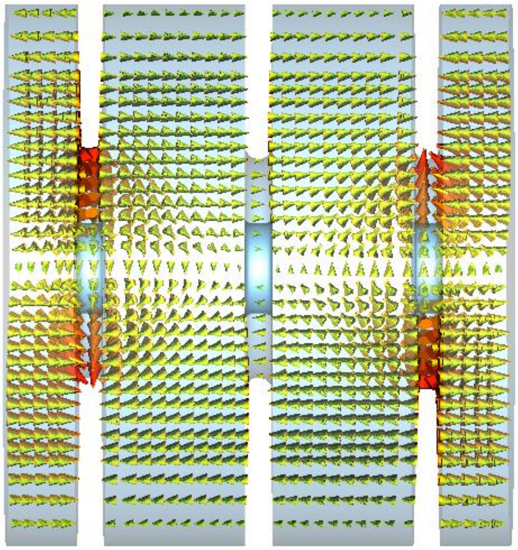
where Q is the quality-factor of the cavity.

DEFLECTING CAVITY

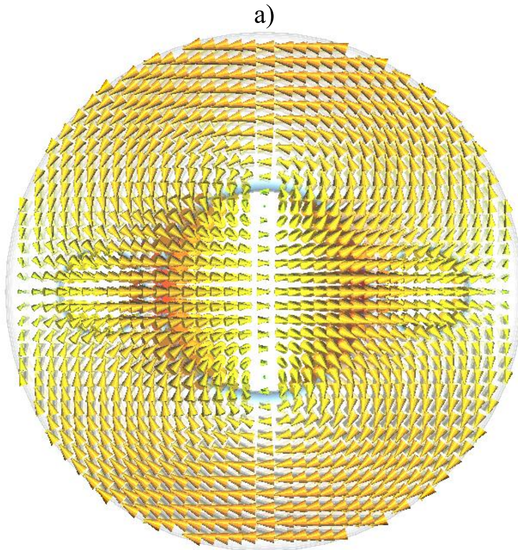
The deflector is being used for kicking electron bunches towards emittance measurement devices. The deflecting structure presented on Fig.1 is a piece of a disk-loaded waveguide operating with TM11 mode at frequency of 2997.2 MHz and it consists of two full cells and two halves. Cell irises have two additional holes for stabilization of the polarization plane.

Figure 1: Deflecting cavity

The TM11 mode being excited with the phase shift of 120 degrees per cell has orthogonal on-axis electric and magnetic fields as shown on Fig.2 a, b.



a)



b)

Figure 2: Electric (a) and magnetic (b) fields

BEAD CALIBRATION

For the measurements, it is necessary to separate electric and magnetic field from each other, and to do that we used two types of perturbing beads. Ceramic bead (ε=8) perturbs electric field only and metallic bead perturbs both components, decreasing the resonant frequency when placed in electric field and increasing it when placed in magnetic field. But the shape of the metallic bead determines how stronger it acts on magnetic field than on electric. The ratio between magnetic and electric form-factors shows the difference in perturbing and therefore the quality of separation.

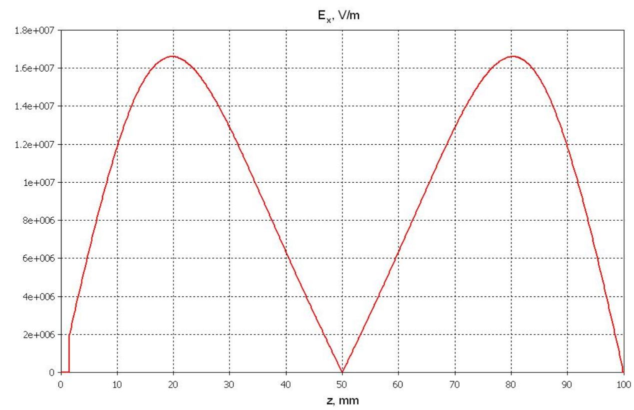
In [4], many types of perturbing beads with different shapes are described.

For example, a very thin metallic ring being placed so that its axis has the same direction with magnetic field has the ratio between its form-factors approximately equals to

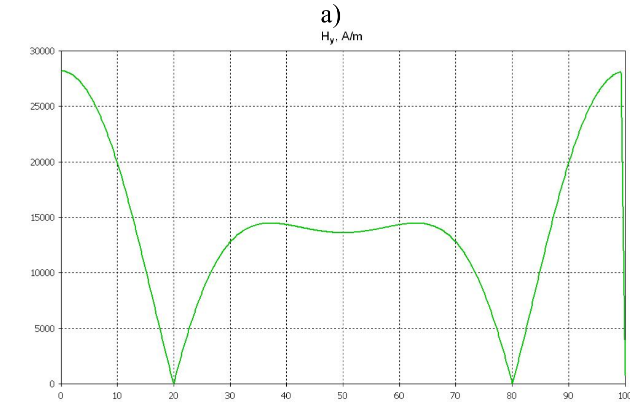
$$\frac{k_H}{k_E} = \frac{\mu_0}{4\varepsilon_0} \frac{(D/d)^2}{\ln(D/d)}, \quad (5)$$

where D is the outer diameter of the ring and d is the ring thickness.

Numerical simulations give us the field magnitudes distributions (E_x, H_y) along the axis and are shown on the Fig. 3 a, b.



a)



b)

Figure 3: Electric E_x (a) and magnetic H_y (b) fields magnitudes

Using these plots, (3) and (5) one can show that k_H/k_E should be higher than $(E_{max}/H_{max})^2$ or 10^5 Ohm^2 for good field separation, and hence the metallic ring must have D/d>100. The copper ring with outer diameter of 5 mm and with thickness of 50 um and the ceramic ball with diameter of 2 mm were being used for the measurements.

In order to measure the form-factors of the beads mentioned we used the cylindrical cavity (R=40 mm, L=103.7 mm) driven with TM010 mode at frequency of 2856 MHz. For this type of resonator, it is very simple to calculate analytically the field strengths on the axis (electric field) and near the cylindrical surface (magnetic field) and the value of stored EM energy. Then we put the beads inside the cavity, measured the frequency shift caused by each bead and calculated the form-factors using the formulas [4], derived from (3):

$$k_E = \frac{|\Delta f|}{f_0} \frac{\varepsilon_0 \pi R^2 L J_1^2(\nu_{01})}{2}, \quad (6)$$

$$k_H = \frac{\Delta f}{f_0^3} \frac{L J_1^2(\nu_{01}) \cdot \nu_{01}^2}{8\pi\varepsilon_0 J_1^2(r \cdot \frac{\nu_{01}}{R})}, \quad (7)$$

with *r=(R–D/2)* – radial position of the metallic ring center.

The results of the calibration coefficients measurements are shown in Table 1.

Table 1: Calibration results

Bead	*Δf*, kHz (on the axis)	k_E, $m^2 s\cdot\Omega^{-1}$	*Δf*, kHz (at the wall)	k_H, $\Omega\, m^2 s$
Ceramic ball Ø2mm	-27	$5.88\cdot10^{-21}$	0	0
Metallic ring D=5mm d=50um	-45	$9.80\cdot10^{-21}$	50	$5.42\cdot10^{-15}$

FIELD MEASUREMENTS

Then we pulled each of the beads along the axis of the cavity with discrete steps of 0.5 mm, and measured the phase shift of S21 with VNA. The results of this procedure are shown on Fig.4. The metallic ring is not perfect because of high k_E, which means that it is necessary to 'subtract' the electric part from the summary perturbation. To do that we used the results obtained with the ceramic bead.

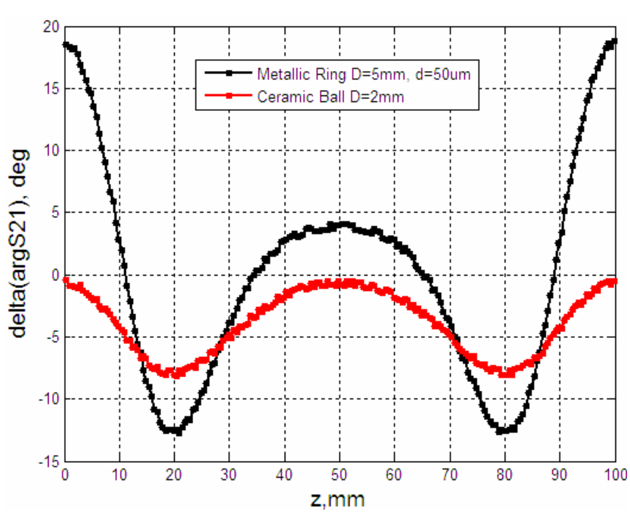


Figure 4: S21 phase shift vs longitudinal coordinate of the beads
(metallic ring – black curve; ceramic ball – red curve)

Using this data and formulas (4), (3) we calculated the field strengths distribution along the axis and the value of transversal shunt impedance with (2). In order to show how the presence of magnetic field acts on the shunt impedance we have also calculated it using electric field only (red curve on Fig.4).

Table 2: Comparison of measurements and MWS

Value	Measurements		MWS Simulations [1]
Q	9800		10800
$r_\perp/Q$, $\Omega\cdot m^{-1}$	Ceramic ball only 1310	Ring+Ball 1550	1590

The total error for $r_\perp/Q$ value includes the mechanical error of phase measurements with VNA and the error of bead calibration. In fact, form-factors are frequency-dependent, which should be taken into account because in our case we calibrated the bead at frequency that differs from the frequency of deflecting cavity by the value of 141.2 MHz. But numerical simulations show that form-factors don't change significantly (less than 1%). An estimation of total relative error gives the value of 5%

CONCLUSIONS

The measurements of transversal shunt impedance of deflecting structure were carried out using the standard technique of resonant field perturbation. The results showed good accordance with CST predictions.

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