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Cross-Talk Problem in Pill-Box Cavity

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Abstract

We discuss the polarisations of dipole modes, excited when a bunch of particles passes a cylindrical cavity beam position monitor. In dependence on the polarisation axis, cross-talk between antennas in x and y directions can be unacceptably strong, in an uncontrolled manner. We propose and apply a solution to get minimal cross-talk between coupling antennas in perpendicular axes.

1 Introduction

Beam Position Monitors (BPM) are devices to measure beam positions in accelerators. Beam position measurements pass the following main stages:

- Pick-Up station

- Signal detection electronics

In this paper we will concentrate on the first stage: **Pick-Up station**.

There are many types of BPMs [1]. Here we will consider cylindrical pill-box BPMs. Its Pick-Up station is a cylindrical cavity with four symmetrically arranged antennas: two for x-position and two for y-position measurements. This box is joint with the beam pipe. An example of such a monitor is shown in Fig.1.

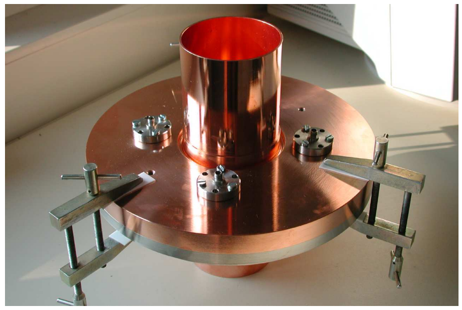

Figure 1: Cylindrical pill-box cavity pick-up station

There is always some signal between the antennas in x and y directions. It means that even if the bunch is deflected in x-direction only, we will detect some signal corresponding to an y-deflection, too. In other words the antennas in perpendicular directions "talk" to each other.

2 Cavity without coupling antennas

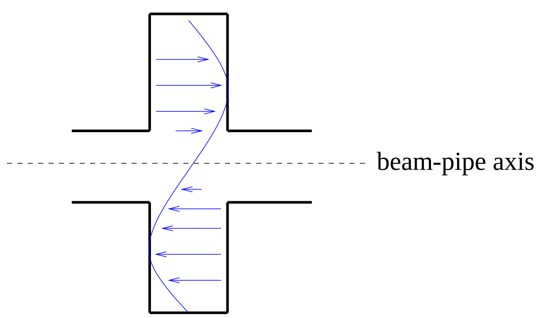

Figure 2: Electric field of the TM_{110} dipole mode in a cylindrical cavity.

When the beam passes through the cavity, resonating fields will be excited. In cavity BPM technique we extract the beam position information from the TM_{110} dipole mode, Fig.2, [2].

In reality there are always some small distortions of the cavity symmetry due to fabrication tolerances, welding procedure, beam-pipe ellipticity etc. All these distortions together can be treated in a simplified manner by considering the cavity as slightly elliptical deformed.

Because of the ellipticity of the monitor two dipole modes with small difference in frequencies are excited, with polarisations perpendicular to each other in coincidence with the axes of the ellipse, Fig.3.

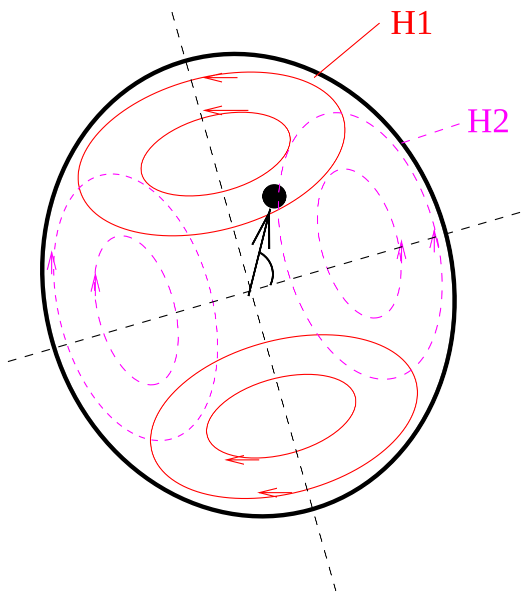

Figure 3: The cut of cylindrical cavity with small ellipticity and magnetic fields of two excited dipole modes. Their polarisations are perpendicular to each other. The black spot imitates the beam.

Now, when the beam goes through the cavity with some displacement two dipole modes are excited with polarisations fixed by the ellipse (see Fig.3), and the larger the beam displacement is the stronger the dipole modes are excited. In dependence of the φ-angle of the displacement one of the two dipole modes will be excited stronger than the other.

The point is that cavity distortions caused by fabrication, welding etc. are out of control. Hence, the orientation of the axis of the ellipse is basically unpredictable.

3 Cavity with four coupling antennas

Antennas also play a role for dipole mode polarisation. When they are perfect symmetrically mounted into the cavity, they force the dipole modes to take one of the two possible polarisations shown in Fig.4a,b, as simulated by the computer code GdfidL [3]:

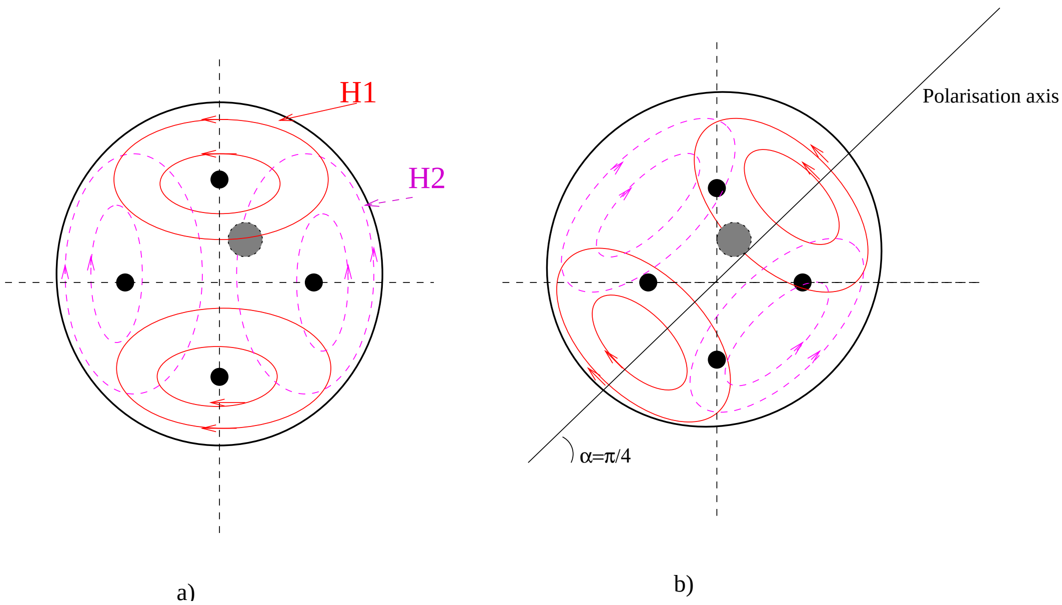

Figure 4: The possible polarisations of the dipole modes in a perfect cavity with four antennas. The small four black spots are the coupling antennas, the bigger one is the beam: a) the dipole mode polarisations are matched with coupling antennas axis. b) the dipole mode polarisations and coupling antennas axes have $\pi/4$ mismatch.

As mentioned in the previous section, there are always some slight distortions of the cavity symmetry, and these distortions decide which case, Fig.4a or Fig.4b, will take place. Again, the beam itself plays no role for selecting the dipole mode polarisation.

4 Reality

Suppose we did good computations and want to build a cylindrical cavity pick-up station with *cross-talk* isolation of 30dB.

It is worth to discuss the following two cases:

1)weak antenna coupling

2)strong antenna coupling

In the case of **weak antenna coupling** distortion effects described in section 2 play the dominant role and effects from the antennas are neglected for dipole mode polarisation. It means that the orientation of the polarisation axis is determined by the orientation of the cavity ellipticity, which can be anywhere. As a consequence, we will get a cavity with better or worse cross-talk performance depending on the angle α, see Fig.5.

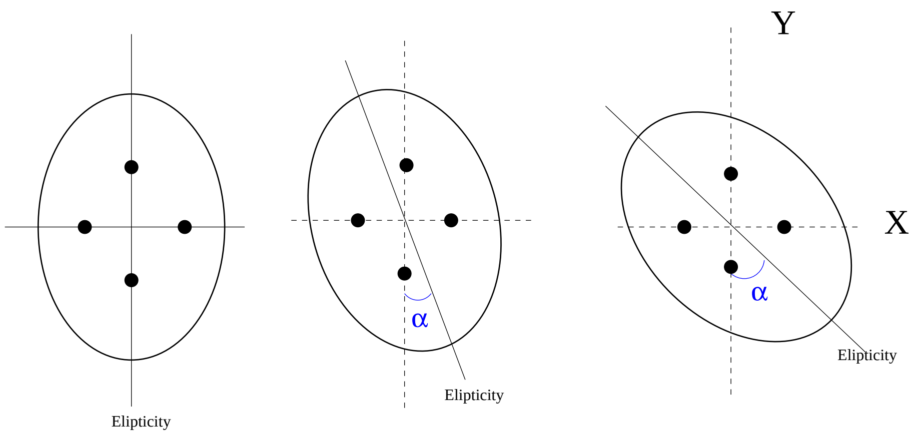

Figure 5: Various locations of the major axis of the ellipse.

Let's discuss the general case, second picture in Fig.5, and the dipole mode corresponding to the major axis of this ellipse. The antenna on y-direction couples the following part from the signal V_{110}^y

$$V_y = V_{110}^y * cos\alpha \tag{1}$$

where V_{110}^y is the amount of the signal which the antenna couples from the mode with polarisation exactly on y-direction, in other words if were $\alpha = 0$ (see [1]). The antenna on the perpendicular x-direction couples the following signal from this mode

$$V_x = V_{110}^y * sin\alpha \tag{2}$$

so that the cross-talk isolation between x- and y-directions in [dB] can be written as

$$Isolation\ [dB] = 20log\left(\frac{V_y}{V_x}\right) = 20log(ctg\alpha) \quad (3)$$

Note that the worst case occurs for $\alpha = 45^o$.

In the case of **strong antenna coupling**, antennas play the main role for fixing the dipole mode polarisation. Now we will get either the desired polarisation (Fig.4a) with best isolation or the polarisation in Fig.4b with no isolation, $\alpha = \pi/4$ (equation (3)).

5 Solution

In order to overcome the problem of unpredictable polarisations of dipole modes and to fix their orientations in a predetermined way we propose the following modification of the cavity. In x- (or y-) direction we generate a relative strong distortion, stronger than all unpredictable distortions discussed so far, for example, by introducing two stamp-eroded rectangular recesses into the cavity [1], as indicated in Fig.6.

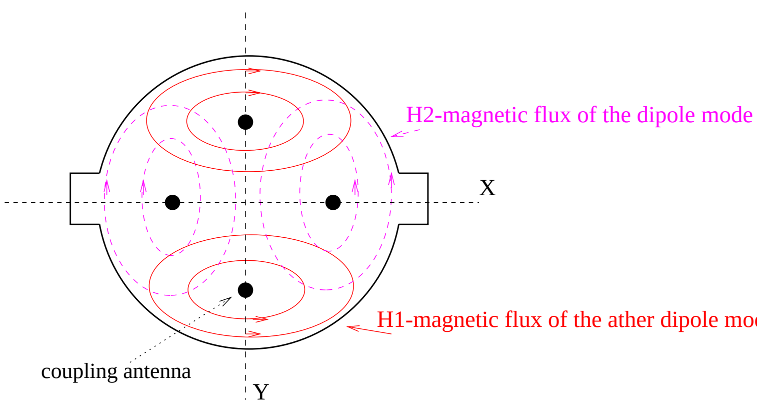

Figure 6: Forced ellipticity with desired orientation of the axis

In this way we force the cavity to behave as an ellipse with its major axis in coincidence with one of the antennas axes. Now, neither slight fabrication distortions nor antennas influences are strong enough to change this desired

[1]Note, that more ellipticity results to bigger difference between the frequencies of the two dipole modes.

polarisation of the dipole modes in unacceptably strong manner.

This proposal has been applied to a prototype of a new cavity BPM for the TESLA cryomodules [4], see Fig.1. We introduced two stamp-eroded rectangular recesses of $64x10mm^2$ with 4mm depth into the cavity with precision of typically $50\mu m$.

Cross-talk isolation measurements were performed as indicated in Fig.7.

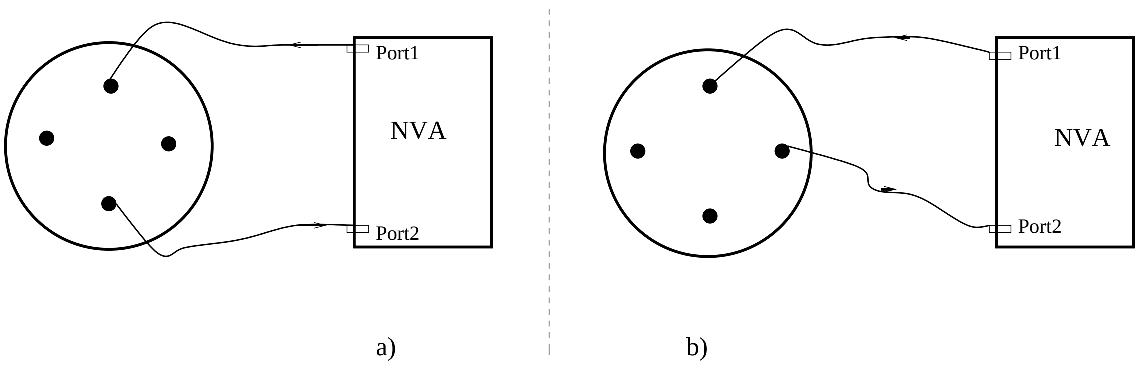

Figure 7: Layout of the measurement

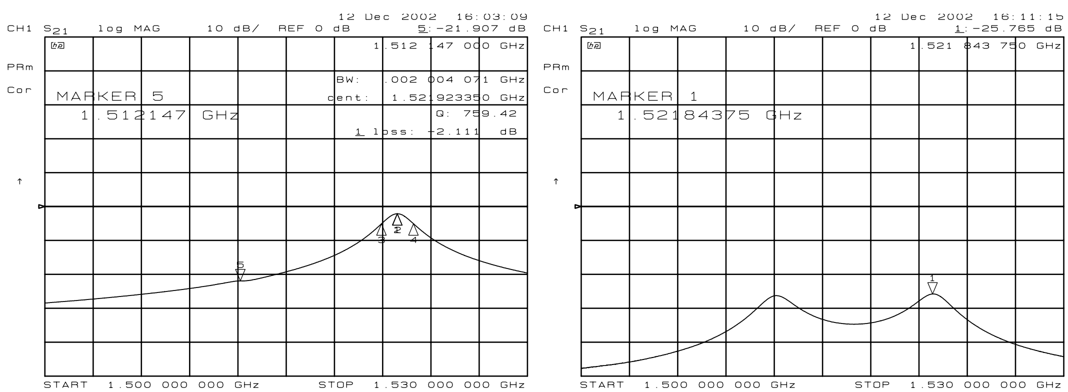

Figure 8: Signal level in [dB] against frequency. The signal level is graded by 10dB. The reference 0dB-line is the middle one of the plots

At first, we generated and coupled the signal through the antennas in the same direction as in Fig.7a. The two remaining coupling ports were loaded by 50Ω. Left plot in Fig.8 shows the result of this measurement. Here signal level is obtained as a function of frequency. A maximum at 1.522GHz with a level of -1.8dB is observed.

Next, we repeated the measurement but using antennas perpendicular to each other (Fig.7b) and obtained the second plot in Fig.8. Here two maxima are visible. The corresponding signal at the second maximum with the same frequency has a level of -25.8dB. The first maximum on 1.512GHz refers to the second dipole mode in perpendicular plane.

The cross-talk isolation value is 24dB signal level difference between left and right plots in Fig.8 on the same 1.522GHz frequency.

Cavity Length	18mm
Cavity Radius	111mm
Pipe Radius	39mm

	without recesses	with recesses
Isolation	0dB	24dB
$f_{H1} - f_{H2}$	300KHz	10MHz

Table 1: Prototype parameters and cross-talk isolation; frequency difference refers to Fig.4 and Fig.6, respectively

Table.1 summarises the results of the measurements before and after stamp-eroded rectangular recesses. The cross-talk isolation is improved from 0dB up to 24dB. The cross-talk between the other ports was about the same.

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