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NEW DESIGN OF A TAPERED-COUPLER BPM TOWARD SIMPLER GEOMETRY AND FLATTER FREQUENCY RESPONSE*

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Abstract

The tapered-coupler stripline beam position monitor has been used for the intra-bunch feedback system in the J-PARC MR. It should be realized with a special shaped stripline whose width is tailored exponentially and whose gap distance between the inner surface of the beam pipe should be also decreasing as a exponential function in order to keep the characteristic impedance at 50 ohm. This 3D varying geometry makes it difficult to achieve the good balance between the electrode responses to the beam. We propose a new design method with a groove, which may give simpler geometry and flatter frequency response.

INTRODUCTION

In J-PARC (Japan Proton Accelerator Research Complex) a 10-year upgrade plan is running in which a proton beam power is to be upgraded from 470 kW to 1.3 MW in the Main Ring [1]. In this process an intra-bunch transverse feedback system plays an important role [2,3]. As operating beam intensity gets higher, growth rate of collective instabilities becomes larger. In addition a wider operating condition search in which betatron tune and/or chromaticity are optimized for a stable incoherent motion sometimes conflicts with the stability of collective motions. It is, therefore, crucial to get the stronger damping of the collective instabilities. We observe the larger Δ-signal in the vertical plane as shown in Fig.1. We are using the tapered-coupler BPM as a position sensor (Fig.2) [3]. Investigation of the bench test data with TDR indicates that one vertical electrode is deformed. Due to the wideband characteristic of this monitor and its high pass filter response, the unbalance seems to become large in high frequencies. It is still unclear because the FIR filter in the signal processing system should reduce the revolution signal, yet we have larger output in the vertical system and cannot raise the loop gain. A good balanced electrode pair needs better machining and assembling of the three dimensionally shaped electrodes, which seems not straightforward. This motivates the new design of a tapered-coupler BPM toward simpler geometry. This design can also achieve flatter frequency response that was difficult in the previous design.

PROPERTIES OF STRIPLINE PICKUPS

The stripline pickup with straight electrode is schematically shown in Fig. 3. The signal is terminated with resistors at both ends. The coupling constant of the pickup which is defined as the induced voltage on the pickup per unit beam current, is constant, k_0, in this case [4]. With the relativistic beam ($v \approx c$) and the electrode length ℓ, we obtain the frequency response as

$$F(\omega) = jk_0 e^{-j\omega\ell/c} sin(\omega\ell/c).$$

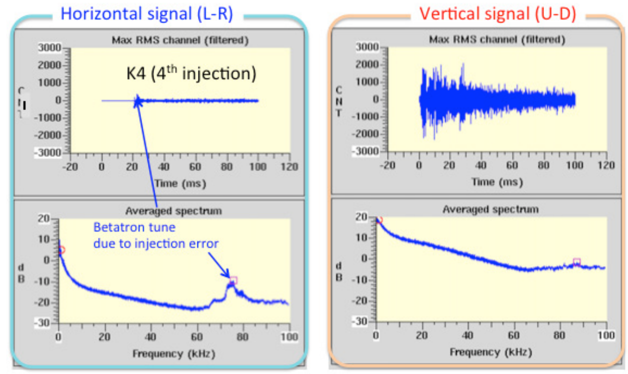

Figure 1: Signals from the left-right pair (left plots) and up-down pair (right plots). Upper plots are time domain signals and lower plots are frequency domain signals.

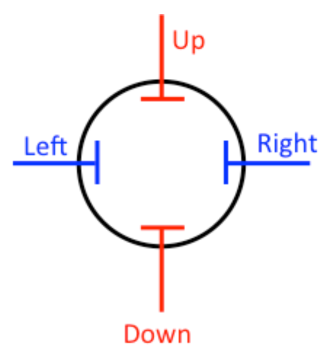

Figure 2: Layout of the BPM electrodes.

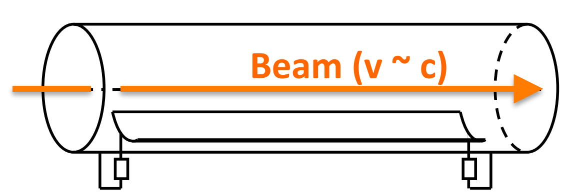

Figure 3: Stripline pickup with a constant electrode width.

In the case of an exponentially tapered stripline as Fig. 4, the coupling constant is $k(z) = k_0 e^{-\alpha z/\ell}$ and the frequency response is

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$$F(\omega) = k_0 \frac{j\omega\ell(1 - e^{-\alpha - j\frac{2\omega\ell}{c}})}{c(\alpha + \frac{2j\omega\ell}{c})}$$

where z is the longitudinal coordinate and α is a constant which decides the exponential decay of the electrode [4,5]. The electrode starts at $z = 0$ and ends at $z = \ell$. In the setup as Fig. 4 the width of the electrode and the gap between the electrode and the inner surface of the beam pipe should go to as small as possible at the downstream end in order to obtain the flatter frequency response. In the case that the coupling constant ends at a certain finite value as shown in Fig. 5 (a), the amplitude and phase responses have ripples in the frequency domain. In Fig. 5 (b) the amplitude response is plotted. When the coupling constant ends at a sufficiently small value, which means the electrode becomes very thin at the end, the response can be close to the simple high pass filter response [5]. Figure 6 suggests this tendency.

In a practical realization of these kinds of shape, 3D varying shape in Fig. 7 is already not easy to machine and assemble. Moreover, achieving the thin end of the electrode adds another difficulty [6].

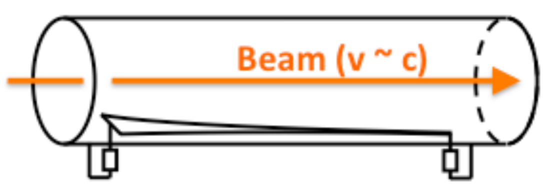
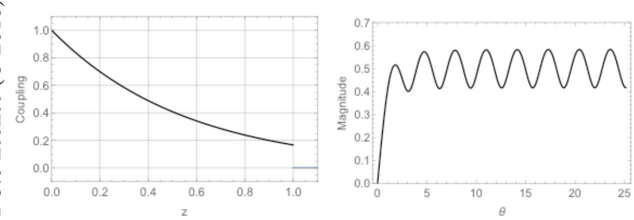
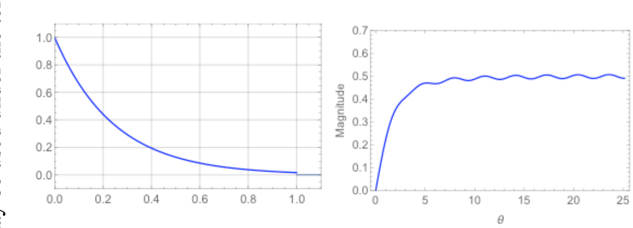


Figure 4: Stripline pickup with an exponential electrode.



(a) (b)

Figure 5: Coupling constant and frequency response with a larger end width.



(a) (b)

Figure 6: Coupling constant and frequency response with a smaller end width.

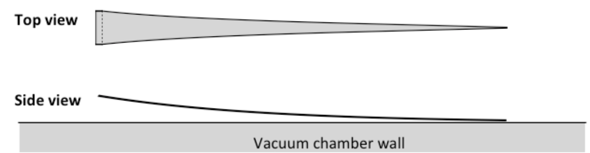
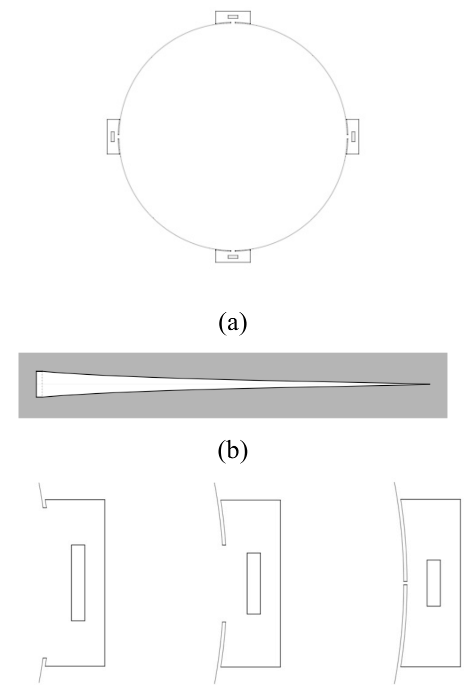


Figure 7: Top and side views of the conventional tapered coupler.

NEW DESIGN

The key of the response is the coupling constant k(z). It should have smooth reduction as an exponential function or other functions of z and approach to zero at the end [6]. It can be realized by other simple geometries with a groove, a slot and a simpler shaped electrode. Two designs are proposed here.



(a)

(b)

(c)

Figure 8: Geometry of the groove, slot and electrode. (a) the detector cross section, (b) the slot and (c) the enlarged cross section of the electrode part, the upstream end to the downstream end from the left to right.

Electrode in a groove covered by a tapered slot

The first design candidate is to set the electrode in the groove and covered by the tapered slot as shown in Fig. 8. The control of the coupling constant is performed with varying the slot width. To keep the characteristic impedance at 50 Ω the electrode width is varied. The example below was optimized with a 2.5D calculation that is a combination of 2D boundary element method and 1D transmission line analysis [7]. Figure 9 (a) shows the amplitude of the frequency response and Fig. 9 (b) is the phase response. Although there still remains a ripple, the flatness is improved comparing with Fig. 5 (b). Better

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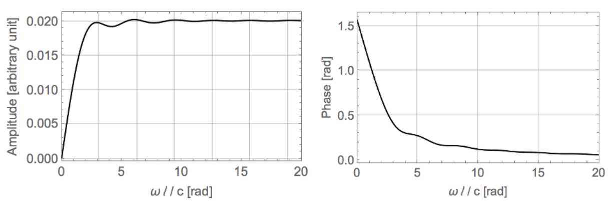
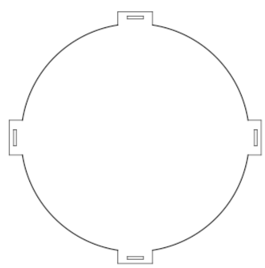
response might be possible with further geometry optimization.



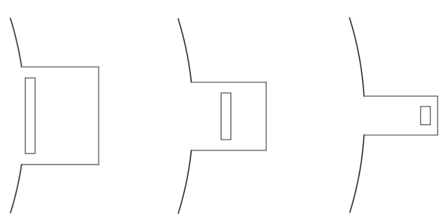
(a) (b)

Figure 9: Frequency response of the electrode in a groove covered by a tapered slot. (a) and (b) are amplitude and phase response in frequency domain, respectively.



(a)

(b)

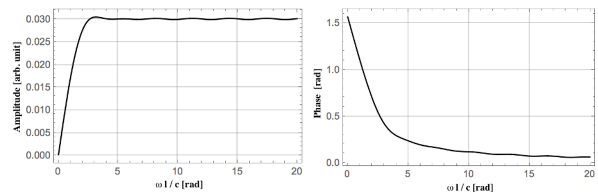


(c)

Figure 10: Geometry of the groove, slot and electrode. (a) the detector cross section, (b) the slot and (c) the enlarged cross section of the electrode part, the upstream end to the downstream end from the left to right.

Inclined tapered electrode in a tapered groove

The second design candidate is to set the inclined tapered electrode in the tapered groove as shown in Fig. 10. There are several parameter choices. One is to vary the groove depth and the electrode width and gap [8] and another is to vary the groove width and the electrode width and gap. The example below was optimized with a latter method and 2.5D calculation as in the previous section. Figure 11 (a) shows the amplitude of the frequency response and Fig.11 (b) is the phase response.



(a) (b)

Figure 11: Frequency response of the inclined tapered electrode in a tapered groove. (a) and (b) are amplitude and phase response in frequency domain, respectively.

CONCLUSION

New designs with simpler electrode geometries are proposed. First one is to set the electrode in the groove and covered by the tapered slot. Another is to set the inclined tapered electrode in the tapered groove. Machining and assembling difficulty seems to be reduced. These structures are estimated to have flatter (small ripple) frequency responses than the previous design with a practical parameter, using 2.5D numerical calculations.

The 3D simulation and manufacturing test setups are on going.

ACKNOWLEDGEMENT

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