DESIGN OF S-BAND CAVITY BPM FOR HLS *

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Abstract

For the development of accelerators we require increasingly precise control of beam position. Cavity BPMs promise a much higher position resolution compared to other BPM types and manufacture of cavity BPMs is in general less complicated. The cavity BPM operating at S-band for HLS (Hefei Light Source) was designed. It consists of two cavities: a position cavity tuned to TM110 mode and a reference cavity tuned to TM010 mode. To suppress the monopole modes we use waveguides as pickups. Superheterodyne receivers are used in electronics for many cavity BPMs while we decide to use chip AD8302 produced by Analog Devices to process the signals. To simulate and calculate the electromagnetic field we use MAFIA.

INTRODUCTION

We have a plan to develop a new injector for HLS, thus an improvement of the beam position monitor system is required. To meet the demand in resolution of the Photocathode RF Gun for new injector design we decided to use cavity BPM instead of the stripline and button BPMs we used in HLS [1] because cavity beam position monitors have relatively higher resolution compared to those old designs [2-4]. Cavity BPM uses a cylindrical cavity mounted into the beam-pipe as pick-up station. When an off-centered beam passes through the cavity it excites electromagnetic field, including TM110 mode. Signal of TM110 mode in the beam-pipe region has a linear dependence on the bunch displacement, so we can use it for beam position monitoring [5]. The TM010 signal is many orders of magnitude larger than the TM110 signal as the beam offset is very small, so we use waveguides as pickups to suppress the TM010 signal and increase the precision [6]. We use electronics for signal detection and computation, then analyze and display the results on computer [7]. As it is mentioned before, the signal of TM110 mode in the beam-pipe region has a linear dependence of the value of the bunch displacement, to get the position of the bunch we still have to get a signal which gives the phase of the displacement, a reference cavity is then developed to give this signal. Though superheterodyne circuits are generally used in signal processing for cavity BPMs, we use chip AD8302 produced by Analog Devices to process the signals. AD8302 can work out the amplitude ratio and phase separation of two signals, so we can use it to process the signals from position cavity and reference cavity and then give the exact position of the beam.

S-BAND CAVITY AND WAVEGUIDE COUPLER

The coupling device could be antennae or waveguides. For higher frequency the antennae may be too tiny, and for lower frequency the size of waveguides may be too large. As the beam offset is very small, the TM010 signal is many orders of magnitude larger than the TM110 signal. We can not use the signal from one pickup to determine the beam position directly. Usual practice is to use a magic-T to subtract the signal of TM010 mode. Another way is to use H-plane of waveguides to couple magnetically to the side of the cavity and then suppress the TM010 mode, and the signal can then be directly used to obtain beam position. This way provides looser tolerances and simplifies the manufacture of the BPM system. The new BPM system will be put into service with Photocathode RF Gun for new injector, so we should select a working frequency of the position cavity around our injector RF frequency, 2856MHz. Since there's heavy interference at 2856MHz and the circuit chip we used has a upper measuring limit of 2.7GHz , we finally decided to use a working frequency around 2652MHz. We do not have to use a frequency exactly at 2856MHz because the BPM system will be used in single bunch case and the frequency spectrum is continuous. Given these conditions we chose waveguides as pickups.
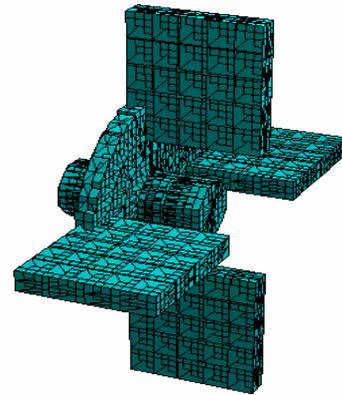

Figure 1: Pattern of the pick-up station

Fig.1 shows the pattern of the pick-up station of the cavity BPM system using MAFIA, the position cavity. A beam pipe passes through the centre of the cavity which four waveguide couplers are installed into it. The parameters of the pick-up station are in Table 1('Distance' is the distance between the bottom of the waveguide and the axis of the cavity, and we set the length of the beam pipe to 80mm):

Table 1: Parameters of the pick-up station

Cavity radius	65 mm
Beam pipe Radius	35 mm
Cavity length	10 mm
Distance	43 mm
Frequency of TM010	1847.2 MHz
Frequency of TM110	2651.3MHz
Q_0 of TM110	7948.5

Waveguides we used have parameters showed in table 2 as pickups. The work frequency of the waveguides can be from 2.50GHz to 3.80GHz.

Table 2: Parameters of the waveguides

Waveguide a	75.0mm
Waveguide b	12.9mm
Waveguide length	82.0 mm

Cavity Radius and Waveguides Adjustments

In actual computation we found that the variation of the TM110 frequency caused by the change of the cavity radius is very small, much less than variation caused by the change of waveguide length and the distance between the waveguide and the axis. The variation of the TM010 frequency caused by the change of the radius is obvious and much larger than that caused by the waveguide adjustment. Fig.2-4 below shows the detail result when the cavity length is set to 40mm.
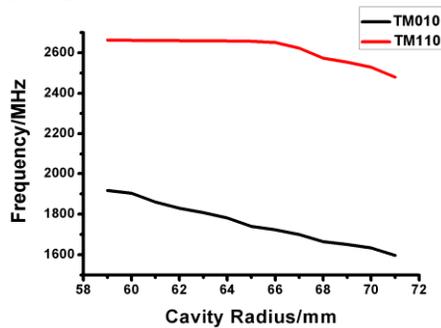

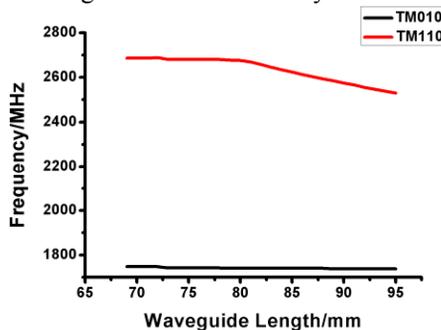Figure 2: Effect of cavity radius
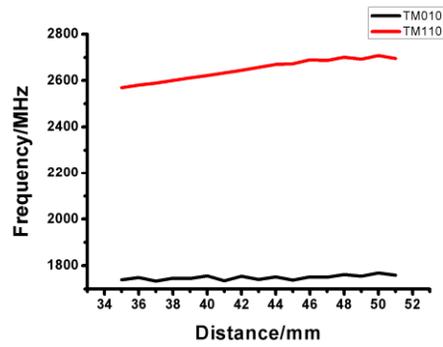

Figure 3: Effect of waveguide length

Figure 4: Effect of distance

Effect of Cavity Length

In Fig.2-4 the cavity length is set to 40mm, in this case the result caused by altering the parameters is more obvious and we can see the effect of waveguide adjustments easily. Reduce the length of the cavity to 10mm that we actually use then we can see the effect of waveguide adjustments is limited, frequency of TM110 mode has a variation of about only 150kHz while length of the waveguides increases 10mm, so the effect of machining tolerance from waveguides is then limited, like Fig.5. In this case, the variation of the TM110 frequency caused by the change of the cavity radius is much larger, like Fig.6.
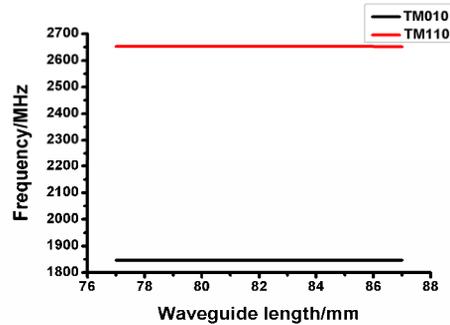
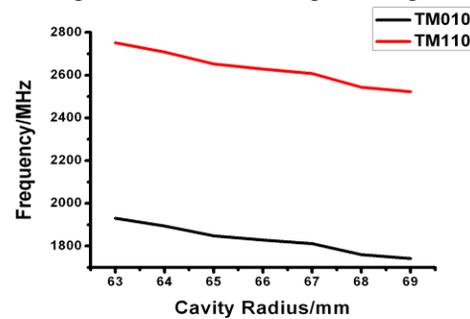

Figure 5: Effect of waveguide length

Figure 6: Effect of cavity radius

REFERENCE CAVITY

Table 3 shows the parameters of reference cavity. The equation (1) [2] shows the relation between output signal and beam offset:

$$V_{cav}(\omega_{110}) = A_1 qx + jA_2 q + jA_3 qx' + V_n \qquad (1)$$

So we need a reference signal to normalize the signal and give the initial phase of the resonance field [2]. To

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provide the signal we use reference cavity. TM010 mode in reference cavity will be tuned to a working frequency at 2652MHz. The TM010 signal from reference cavity is proportional to the beam current and will be used to normalize the position signal from position cavity.

Table 3: Parameters of the reference cavity

Radius	47.7mm
Length	10.0mm
Frequency of TM010 mode	2653.9MHz
Q_0 of TM010 mode	6682.8

ELECTRONICS

The usual method is to use superheterodyne receivers in electronics for many cavity BPMs. Obviously we can use circuit chips instead of superheterodyne receivers to complete the process and simplify our work. Chip AD8302 from Analog Devices bases on the logarithmic compression function of logarithmic amplifier and uses two broadband logarithmic detectors that matches well to measure the magnitude and phase of the signals from two input channels. The AD8302 is a fully integrated system for measuring gain/loss and phase in numerous receive, transmit, and instrumentation applications. The input signals can range from –60 dBm to 0 dBm in a 50 Ω system, from low frequencies up to 2.7 GHz. The outputs provide an accurate measurement of either gain or loss over a ±30 dB range scaled to 30 mV/dB, and of phase over a 0°–180° range scaled to 10 mV/degree[9]. The block diagram of cavity-BPM detection circuit is shown in Fig.7. AD8302 will give the magnitude and phase signals. We can use computer to process them and then figure out the exact position of the beam. By using the chip AD8302 we can get an electronic system with more dynamic range and higher precision. Using the logarithmic RF amplifier, the signal processing system has large dynamic range.
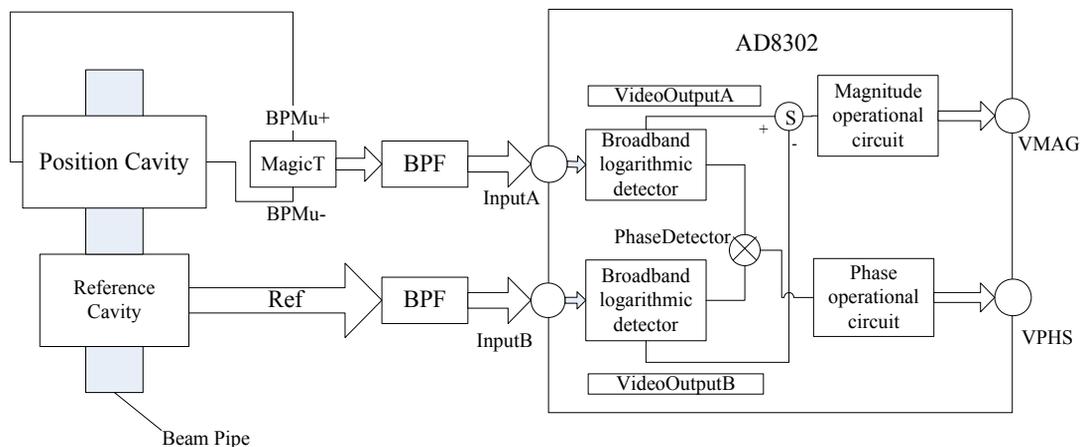
SUMMARY

We have designed the prototype cavity BPM working at TM110 mode, 2652.0MHz. Application of waveguides as pickups will suppress the interference from TM010 mode of resonance field. Use chip AD8302 to simplify the signal processing is a novel design in some way and we hope it will be of benefit to dynamic range and precision of electronics. The cavity beam position monitor system will help to improve the performance of HLS beam diagnostics system. Further work will be concentrated on the manufacture of the prototype cavity BPM and the signal processing system using AD8302.

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Figure 7:   Block diagram of cavity-BPM detection circuit with AD8302