DESIGN AND COLD TEST OF RE-ENTRANT CAVITY BPM FOR HLS*

Q. Luo#, B.G. Sun, Z.R. Zhou, Q.K. Jia
NSRL, School of Nuclear Science and Technology, University of Science and Technology of China, Hefei 230029, P. R. China

Abstract

An S-band cavity BPM is designed for a new injector in National Synchrotron Radiation Laboratory. A re-entrant position cavity is tuned to TM110 mode as position cavity. Theoretical resolution of the BPM is 31 nm. A prototype cavity BPM system is manufactured for cold test. Wire scanning method is used to calibrate the BPM and estimate the performance of the on-line BPM system. Cold test results showed that position resolution of prototype BPM is better than 3 μm. Cross-talk has been detected during the cold test. Racetrack cavity can be used to suppress cross-talk. Ignoring nonlinear effect, transformation matrix is a way to correct cross-talk.

INTRODUCTION

The high brightness injector of Hefei Light Source (HLS) is designed for the development of new techniques of linac-based free electron laser (FEL), which could be the most probable scheme of the fourth generation light source. To get high quality beam [1], high precision control of the beam position is requested. In recent years, cavity BPM is developed as a novel method that promises very high position resolution of beam [2]. Position resolution of the beam position monitor (BPM) for the photocathode RF gun of the new injector should be better than 10 μm. For a substantial improvement in position resolution of BPM system, HLS decided to use cavity BPM, which promises much higher position resolution than the stripline BPM used at HLS before [3].

In this paper, a re-entrant position cavity, instead of an ordinary pill-box cavity, is used to reduce the system size and the Q factor as well. The signal detected from TM110 mode has a linear dependence on absolute value of bunch displacement [4-7]. A reference cavity tuned to TM010 mode is needed for reading the sign of bunch displacement. The ideal position resolution could be 7 nm. With a noise factor of 10 from the electronics, the theoretical resolution is 31 nm.

Prototype of the s-band cavity BPM is manufactured and cold test is then performed. The position resolution of cavity BPM system on-line can be better than 3μm.

Cross-talk problem caused by unpredictable distortions [8] is observed. Racetrack cavity BPM design is a way to suppress the cross-talk [9]. When nonlinear effect is negligible, transformation matrix can be used to distinguish position signal from cross-talk noise.

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#luoqing@ustc.edu.cn

RE-ENTRANT CAVITY BPM

A re-entrant cavity is used as position cavity in pick-up station. Re-entrant cavity has much smaller size and much lower Q factor than a pill-box cavity with same resonant frequency of TM110 mode. Size of the system can be controlled and proper waveguide be chosen easily.

Fig. 1 shows parameters of the design. The thickness of metal walls is changeable so only vacuum part of pick-up station is showed. The demensions (in mm) are: R_{in} 44.000, R_{out} 47.900, L_1 30.304, L_2 10.000, a 70.000, b 10.000, L_{wg} 65.000, Z_{coax} 55.060 and R_{coax}, 55.050.Coaxial feed-through used in the design is SMA type feed through NL-108-546, produced by Hitachi Haramachi Electronics Co., Ltd.

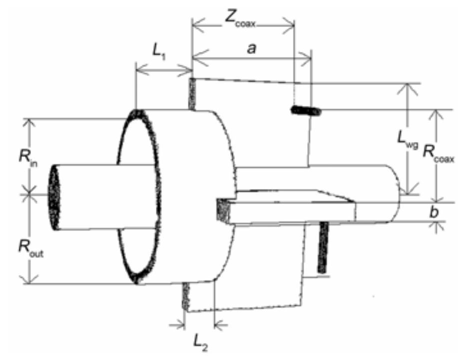

Figure 1: Structure of vacuum part of BPM.

The position resolution is the minimum displacement for the electronics to get a signal voltage higher than thermal noise. If the electronics is ideal (noise factor *NF* =1 and all the energy loss in TM110 mode is coupled out to the electronics [10], there will be

$$\Delta x_{ideal} = \frac{1}{q}\sqrt{\frac{4kT(1+\beta)}{\pi\beta k_{loss,nml}}} \quad (1)$$

where $k_{\text{loss, nml}}$ is loss factor of TM110 mode normalized by bunch displacement and β is the coupling factor (the ratio between no load Q and external Q).

In computer simulation, Q_0 is 3913.8, Q_e is 298.1 and $k_{\text{loss, normalized}}$ = 1.14 $\times 10^{14}$ $\Omega\cdot m^{-2}\cdot s^{-1}$. The electronics get about 52% of total energy loss in TM110 mode. Assume that *NF* of electronics is 10 and then the theoretical resolution can be gotten from equation (1)

$$\Delta x_{theoretical} = \frac{1}{q}\sqrt{\frac{4kT(1+\beta)}{\pi\beta k_{loss,110,nml}}}\sqrt{\frac{NF}{0.52}} \quad (2)$$

When bunch charge is 1 nC, the ideal resolution is 7 nm and the theoretical resolution is 31 nm. The external Q of monopole mode obtained from simulation is 2.6×10^{13}, the monopole mode is successfully suppressed.

COLD TEST AND ANALYSIS

A prototype cavity made of duralumin is manufactured for cold test. Here duralumin is used because it works easily and is cheap and light.

Two cold test methods are used to study the prototype cavity and estimate the performance of the on-line BPM system. Network analyzer is used to get the transmission characteristic of prototype cavity. To estimate the position resolution, displaced analogue signal at the resonant frequency of TM_{110} mode is input to the prototype cavity to simulate displaced beam and oscilloscope is used to get the amplitude of response signal coupled out from the probes. Fig.2 shows the definitions of ports used in cold test and Fig. 3 shows sketch of wire scanning calibration platform.

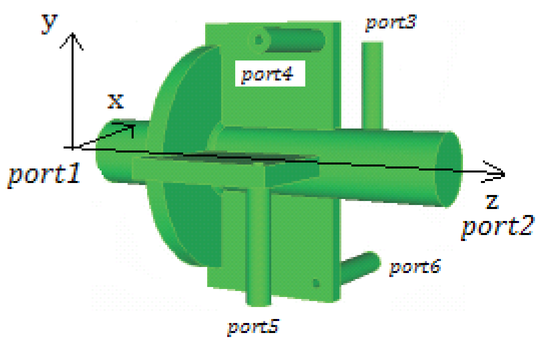

Figure 2: Definition of ports used in cold test.

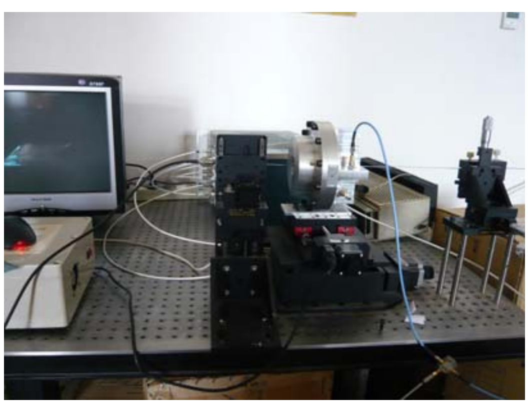

Figure 3: Sketch of the calibration platform.

Fig. 4 shows the transmission characteristic curve from port 3 to port 4. Two peaks of dipole modes under -25dB can be found, so there is x-y coupling about 5%-10%, which means there are distortions.

The curves shown in Fig. 5 and Fig. 6 describe how the signal amplitude responses to displacement of the metal wire. The oscilloscope is set to average mode so as to reduce the error. The amplitude of excitation signal is 1.5V while the frequency is same as the resonant frequency of TM_{110} mode.

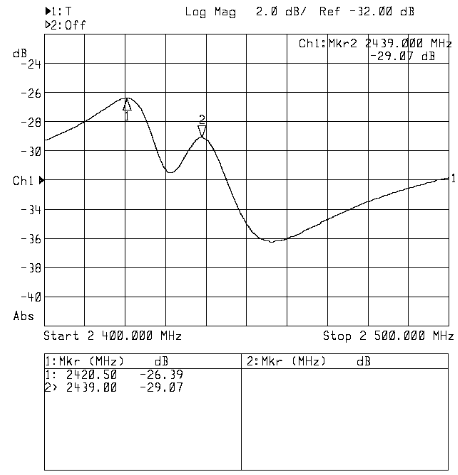

Figure 4: x-y transmission curve.

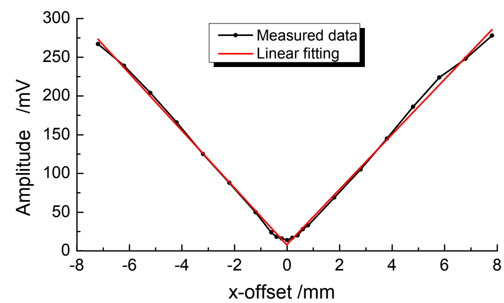

Figure 5: Amplitude vs x displacement.

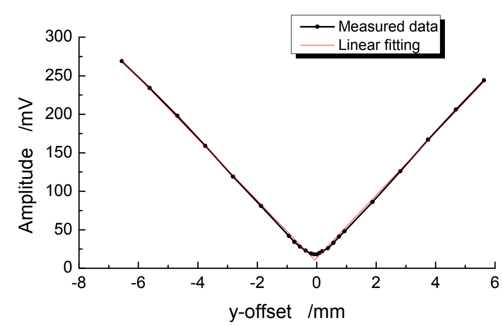

Figure 6: Amplitude vs y displacement.

Least square method was used in analyzing the results of experiments. Amplitude sensitivity in x direction is 40.1mV/mm， while in y direction it is 41.5mV/mm.

The off-line test resolutions in different directions are shown below:

$$\begin{cases} \langle d \rangle_x = 0.0183\text{mm} \\ \langle d \rangle_y = 0.0188\text{mm} \end{cases} \quad (3)$$

Amplitude sensitivity on-line can be treated as the same as theoretical value [11]:

$$\begin{cases} \eta = \dfrac{2}{\pi}\operatorname{arctg}\left(\dfrac{\Delta F Q_{L,110}}{f_{110}}\right)\dfrac{Q_{0,110} - Q_{L,110}}{Q_{0,110}} \\ V_{110}^{out} = qr\sqrt{Z_0 \eta \dfrac{k_{loss,110,nml}}{2}\dfrac{\omega_{110}}{Q_{e,110}}} \end{cases} \quad (4)$$

Sensitivity on-line is 382.9mV/mm in x direction and 381.9mV/mm in y direction, larger than it is off-line, generally because the excitation is much stronger. The real resolution can be estimated as below:

$$\begin{cases} \delta_x = 0.0183 \times 40.1 / 382.9\text{mm}=1.91\mu\text{m} \\ \delta_y = 0.0188 \times 41.5 / 381.9\text{mm}=2.05\mu\text{m} \end{cases}$$

The real resolution may be better because the precision of oscilloscope is limited. The maximal measurement error is 1mV. In order to get results in greater precision, an s-band RF signal receiver is needed.

CROSS-TALK CORRECTION

The cross-talk is mainly caused by linear coupling. Assume that there's only linear coupling, the coupling can be described by a matrix $M_{coupling} = \begin{pmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{pmatrix}$. Because of conservation of energy, the matrix satisfies:

$$\begin{cases} C_{11}^2 + C_{21}^2 = 1 \\ C_{12}^2 + C_{22}^2 = 1 \end{cases} \quad (5)$$

So the coupling matrix can be solved from a system of binary equations formed by the measurement results. The linear coupling is then corrected.

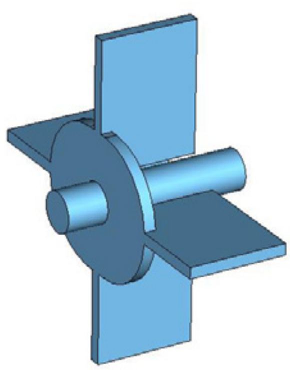

Figure 7: Sketch of racetrack cavity BPM.

Mechanic errors and distortions result in cross-talk problem. If asymmetrical structure such as a racetrack cavity BPM is used, linear coupling from distortions can be suppressed [9]. Fig. 7 shows a racetrack cavity.

FUTURE PLAN

As it is mentioned before, precision of oscilloscope is limited. To get higher beam position resolution, high precision signal processing system is required.

Libera digital processors developed by Instrumentation Technologies, d.o.o are widely used as beam position processors. In NSRL, USTC there is a plan to establish a digital beam diagnostic system consists of Liberas and other equipments for the HLS storage ring, including a cavity BPM signal processing system using Libera.

CONCLUSIONS

Re-entrant cavity BPM is a good solution for high precision control of beam position and it can reach a high resolution better than 3 µm. With high precision RF signal processing system the performance of cavity BPM system can still improve. Cross-talk from distortions could be a problem to cavity BPMs. Transformation matrix is a way to correct cross-talk when nonlinear effect is negligible.

ACKNOWLEDGEMENTS

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