COLD TEST OF S-BAND RE-ENTRANT CAVITY BPM FOR HLS*

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Abstract

An s-band re-entrant cavity BPM system is designed for new high brightness injector at HLS. A prototype cavity BPM system was manufactured for off-line test, which is also called cold test. According to the results of computer simulation, wire scanning off-line test method can be used to calibrate the BPM and estimate the performance of the on-line BPM system. Cross-talk problem was detected during the cold test. Ignoring nonlinear effect, transformation matrix is a way to correct cross-talk. Analysis of cold test results showed that position resolution of prototype BPM is better than 3 μm.

INTRODUCTION

The high brightness injector at HLS was designed for the development of new technologies of the fourth-generation light source. The fourth-generation light sources have higher brightness, higher coherence and shorter optical pulse, thus high quality electron bunch with high beam brightness, low emittance, low beam energy spread and high current is required [1]. To develop high quality electron source, it is important to improve the performance of BPM system to steer the beam along the optimal trajectory. The 4~5 MeV RF photocathode gun of the new injector in HLS was set up to produce high brightness beam with the transverse normalize emittance of 6mm-mrad for a bunch charge of 0.3 nC. Since the positional resolution of BPM should be less than 10μm, a cavity BPM [2], which promises much higher position resolution compared to other types of BPMs [3], was designed to replace the stripline one [4] set up for HLS linac before. Performance of cavity BPM system on-line can be reflected by off-line performance of the prototype and wire scanning method can be used to calibrate the cavity BPM system. Prototype of the s-band cavity BPM was manufactured and cold test using network analyzer and oscilloscope was then performed. Results from cold test of prototype were analyzed to estimate the performance of cavity BPM. The position resolution of cavity BPM system on-line can be better than 3μm. During the cold test cross-talk problem caused by unpredictable distortions [5] was observed. Racetrack cavity BPM design is a way to suppress the cross-talk [6]. When nonlinear effect is negligible, transformation matrix can be used to distinguish position signal from cross-talk noise.

CAVITY STRUCTURE

Pick-up station of the re-entrant cavity BPM designed for photocathode gun of HLS high brightness injector consists of a re-entrant position cavity and a cylindrical reference cavity [2]. Working frequency is 2448MHz. Cut-through waveguides and coaxial probes are installed to pick upTM_{110} mode signals. Sketch of the cavity BPM is illustrated in Fig. 1.Ports are defined to simplify the description of measurement.

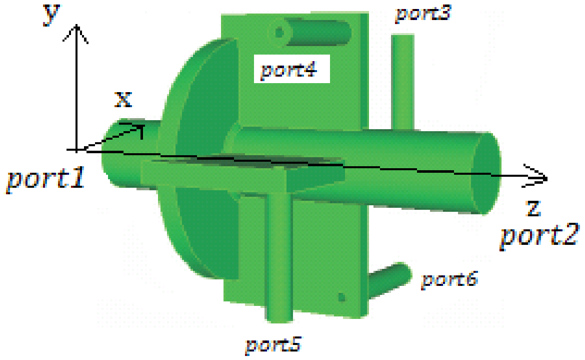

Figure 1: Sketch of the cavity BPM.

COLD TEST METHOD

To study the eigenmodes of the cavity and estimate the performance of the BPM system, two cold test methods were used. Network analyzer was used to measure the transmission characteristic of prototype cavity. Oscilloscope was used to measure the amplitude of response signal coupled out from the probes when displaced analogue signal at the resonant frequency of TM_{110} mode was input to simulate displaced beam.

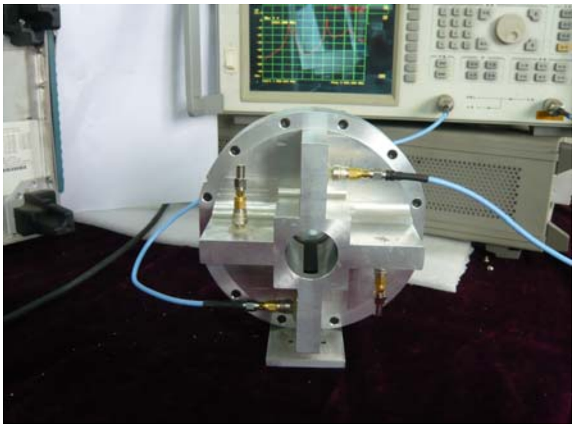

Figure 2: Measurement with network analyzer.

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Resonant frequencies and amplitudes of eigenmodes can be read in transmission characteristic curves. Fig.2 shows how to measure the transmission between port 4 and port 6.

Wire scanning method is an off-line calibration method. Analogue signal is feed into the resonant cavity by a straight metal wire to simulate the beam. Eigenmodes of the cavity are then excited. Measure the amplitude of the TM_{110} mode signal response to the wire displacement, the cavity BPM system is then calibrated.

Microwave Studio software was used to simulate the cavity structure with a thin metal wire through it. According to the simulation results, when the wire is very thin compared to the cavity radius, the resonant frequencies and shunt impedances of the eigenmodes can be treated as remain the same as there's no wire through the cavity. This means off-line wire scanning method is an effective way to calibrate the cavity BPM system.

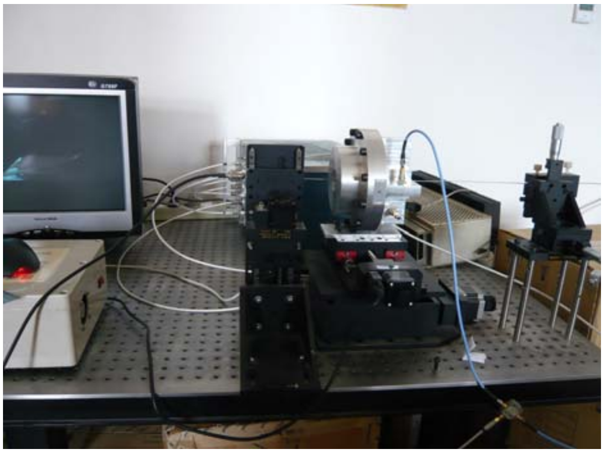

Figure 3: Sketch of the calibration platform.

TRANSMISSION CHARACTERISTICS

Fig. 4 shows the modes that the signal excited in the prototype cavity. TM_{010} mode can be found at 1730MHz, while TM_{110} mode can be found at 2440MHz. Peaks between them are waveguide modes.

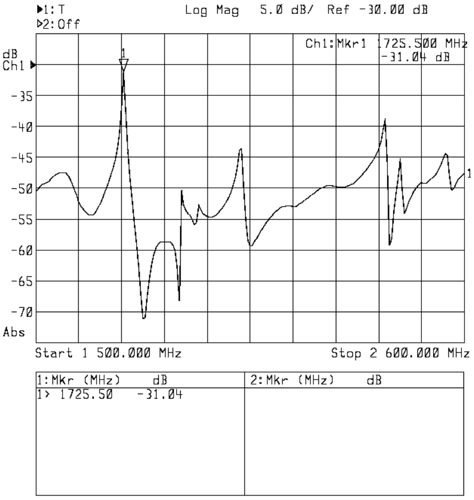

Figure 4: Transmission curve from port1 to port2

A loaded Q of 146 was got from the resonant frequency and bandwidth found in Fig. 4. Coupling between x-direction and y-direction can be found from transmission curves between ports defined at pick up probes (port3-6). For example, Fig. 5(a) and Fig. 5(b) show the transmission curve between port3 and port4.

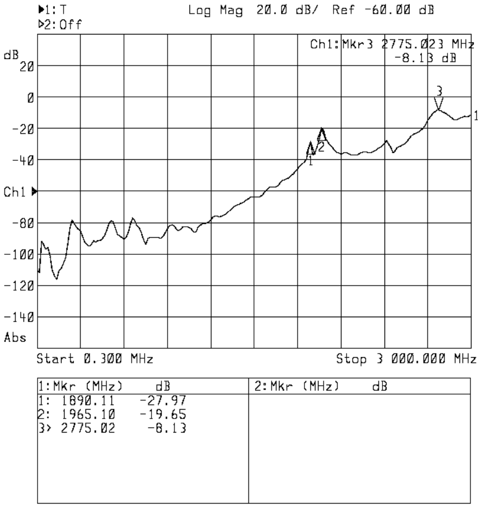

Figure 5(a): Transmission curve from port3 to port4

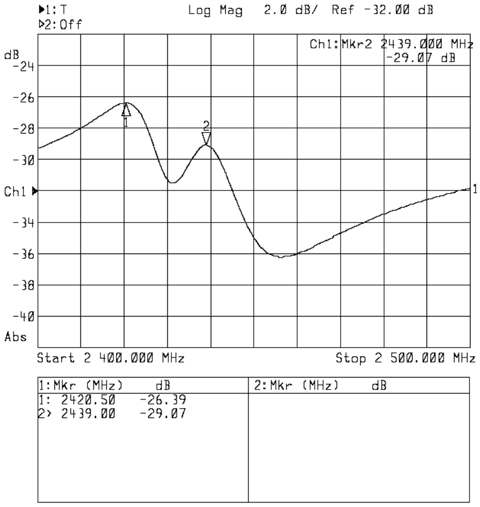

Figure 5(b): Transmission curve from port3 to port4

Three waveguide modes above -30dB can be found in Fig. 5(a) and two peaks of dipole modes under -25dB can be found in Fig. 5(b). So there is x-y coupling, about 5%-10%. This means there is cross-talk caused by distortions.

WIRE SCANNING TEST

To get the amplitude of TM110 mode signal oscilloscope was used. The oscilloscope was set to average mode so as to reduce the error. The curves shown in Fig. 6 and Fig. 7 describe how the signal amplitude responses to displacement of the metal wire. The amplitude of excitation signal is 1.5V while the frequency is same as the resonant frequency of TM_{110} mode.

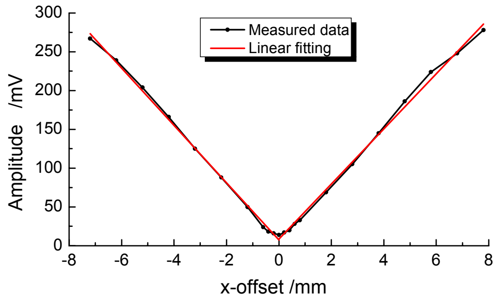

Figure 6: Amplitude vs x displacement

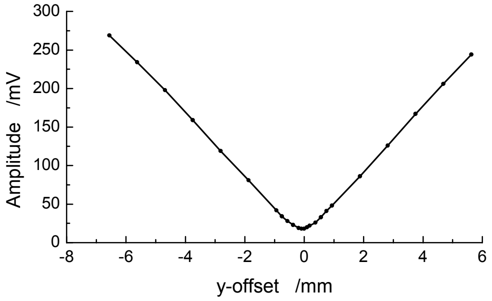

Figure 7: Amplitude vs y displacement

Resolution of the Cavity BPM

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:

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

Amplitude sensitivity on-line can be treated as the same as theoretical value that can be figure out [2]:

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

The 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 of the excitation is much stronger. The real resolution can be estimated as below:

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

In fact the real resolution may be better because the precision of oscilloscope is not very high. The measurement error may be as large as 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:

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

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

CONCLUSION

The prototype of s-band cavity BPM was manufactured and tested off-line. It is proved that cavity BPM can reach a very good resolution better than 3 μm. To get cavity BPM system with better resolution, high precision RF signal processing system is needed. Ignoring nonlinear effect, transformation matrix is a way to correct cross-talk.

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