FABRICATION AND PERFORMANCE TEST OF THE CAVITY BPM FOR KEK ATF2 AND PAL XFEL*

J. Y. Huang[#], S. H. Kim, Y. J. Park, W. H. Hwang, S. J. Park, *PAL, KOREA*
Y. Honda, H. Inoue, T. Tauchi, J. Urakawa, *KEK, Japan*
M. Ross, *FNAL, USA*

Abstract

A high-resolution beam position monitor (BPM) based on a pill-box type microwave cavity has been developed for the accurate beam position measurement in the KEK-ATF2. Based on the prototype cavity BPM designed in the KEK, the cavity structure and the isolation between horizontal and vertical modes are further improved by the collaboration between KEK, SLAC and PAL. The resonant frequency of the cavity and the isolation between horizontal and vertical modes can be tuned efficiently using tuning pins brazed on the cavity rim instead of the conventional tuning plunger. Offset between electrical and mechanical centers could be reduced by tuning within +/- 5 um, the isolation tuned better than 50 dB, and the 100 nm resolution of the cavity BPM has been proved through the beam tests in the ATF extraction beamline. Technical design considerations, fabrication, and test results of the cavity BPM are described in this paper.

INTRODUCTION

In the next generation linear accelerators like the International Linear Collider (ILC)[1] and the X-ray Free Electron Laser (XFEL)[2,3], precise beam trajectory control as well as the beam-based accelerator alignment are very important for achieving nanometer-sized beams at the interaction point (IP) of the ILC or keeping the orbit stability better than a few micrometers in the XFEL for the stable FEL amplification along the undulator. A Resolution as good as 100 nanometers and a long-term stability within a few micrometers are required for the beam position monitors (BPM). Although BPMs with pickup electrodes or striplines have been improved for a better resolution, it has been limited to a few micrometers. For the ultra-short, high peak current bunches, a pill-box type cavity BPM has been considered as a promising candidate providing higher electrical sensitivity and mechanical stability. In a cavity BPM, a beam with a position offset from the electrical center excites large signal of TM110 transverse dipole mode. This signal is coupled to a waveguide through a coupling slot, and then picked up with a pickup electrode positioned at the waveguide wall.

The KEK-ATF2 [4] is an advanced accelerator test facility being built by extending the extraction beamline of the existing ATF to test advanced beam diagnostic systems and beam dynamics required for the final focus area of the ILC.

Three prototype cavity BPM have been developed and fabricated for the KEK-ATF2. With the successful results from beam tests done in the ATF, 11 cavity BPMs have been produced. The remaining 28 cavity BPMs are being fabricated by the PAL and will be installed in the KEK-ATF2.

PROTOTYPE DESIGN AND FABRICATION

Design of the cavity and waveguide structure of the cavity has been done in the KEK with computer simulation codes, and a prototype cavity BPM was fabricated and tested in the KEK-ATF by Y. Honda. A C-band cavity tuned at 6.426-GHz TM110 dipole mode was selected as the pickup cavity. Mechanical and electrical design parameters of the cavity BPM are summarized in the Table 1 [5].

Table 1. Design parameters of the cavity BPM

Tuned frequency	6.426 GHz
Resolution	100 nm
Dynamic range	500 um
Isolation (x/y)	< -30 dB
Q_0	> 5000
Offset of e-center	< 10 um
Coupling	> 0.3

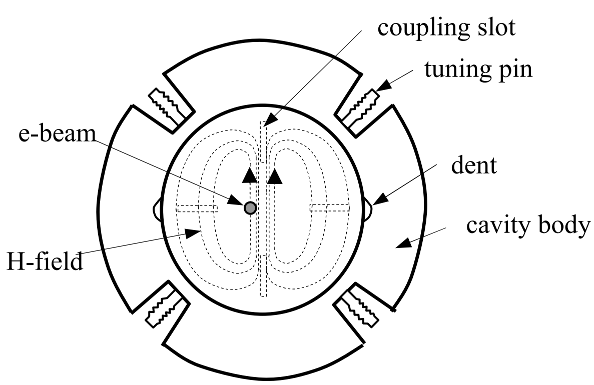
Offset of the beam excites TM110 transverse magnetic mode in the cavity and the signal is coupled to the electrical pickups in the waveguide through four 1.5 x 13 mm^2 rectangular coupling slots. (See Fig. 1) Waveguide structure was optimized to reduce reflections, to increase coupling, and to reject common modes.

Two variations of the prototype cavity BPMs - a perfect cylindrical cavity, and a cavity with two dents on the symmetrical positions along the inner rim of the cavity to enhance the mode separation - are fabricated and tested for comparison of isolation between horizontal and vertical modes. Fig. 1(a) shows the schematic for the two types of the prototypes. Pair of 0.1-mm dents made with 6-mm milling drill (cavity diameter = 53.822 mm) on the inner surface of cavity rim has given resonance frequency shift of 500 kHz.

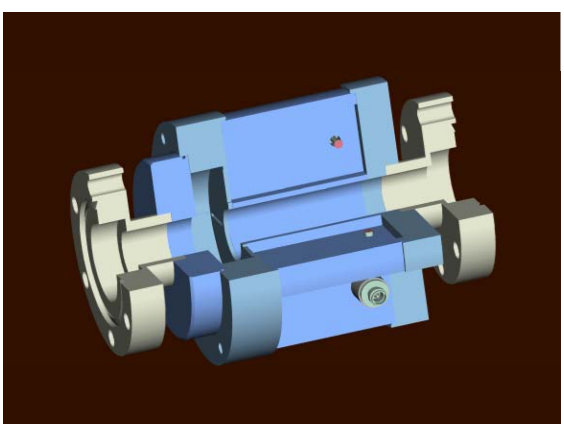
The effects of machining errors and deformations of the cavity components are tested before the final design. The 1- mm thick septum for the coupling slot between the cavity and the waveguide was found to be deformed during brazing, so the thickness was increased to 1.5 mm. For the compensation of the mechanical error of the cavity, four tuning pins are brazed into the recess of cavity body on the diagonal positions of the cavity. Tuning pins can push or pull cavity wall slightly for the compensation and cancellation of the mechanical errors, such as volume and symmetry of the cavity. Fig. 1 shows the schematic of the cavity with and without dents.

Machining accuracies are tightly controlled during machining using special jigs. Surface roughness of the cavity wall is better than R_{max}< 0.8 um by using diamond tools. Overall errors of the prototype cavity measured with 3-dimensional profiler were kept within 10 um.

Brazing procedure has been also investigated through trial and errors before the final brazing finding out optimum thickness of brazing alloys and appropriate shape of brazing alloy slots to reduce spill-out of the brazing alloy. All of the cavity BPM parts are brazed at the same time with a special brazing jig to reduce deformations which can occur during multiple brazing processes. Brazing temperature is chosen to be 720 C as the signal pickup feedthrus had been brazed at 780 C.



(a)



(b)

Figure 1: Schematics of cavity BPM. a) Cross-sectional view the cavity across the beam path showing tuning pins and coupling slots. Dents are carved for the test only. b) Computer aided assembly drawing of the cavity BPM.

MEASUREMENTS

Mechanical Measurements

Mechanical dimensions of all parts are measured with precision 3-D profiler before brazing. Fig. 2(a) shows a cavity body being set up on the 3-D profiler for the measurements. Mechanical errors of all the components come within 10 um, well below the design requirement of 20 um. Table 2 summarizes the test results.

Figure 2(a): A cavity body set up on the 3-D profiler for the dimensional check. b) A cavity BPM assembled in a tightening jig for the microwave measurements before brazing.

Microwave Measurements

Resonance frequency, reflection and transmission of the cavity ports are measured with the HP8510C network analyzer before and after brazing. The resonance frequency has increased 1 ~ 2 MHz after brazing, and further increased by 2 MHz when the cavity was evacuated. The cavity frequency was tuned up with an increase of 1.3 MHz in average. From this result, the cavity size will be 18 um reduced for the final production of 28 cavity BPMs. Quality factor of the cavity is better than 5000.

Mechanical and electrical center of the cavity has been measured by an antenna setup invented by H. Inoue in KEK. The offset came within 5 um accuracy well below the requirement of < 10 um.

Table 2. Results of the mechanical and microwave measurements for production model.

Parameters	Before brazing	After brazing		Design Value
		Before tuning	After tuning	
Frequency (GHz)	6.42158	6.42418	6.42548	6.42600
Isolation (dB)	23.7	25	46.6	> 30
Q_L	random	> 5000	6025	> 5000
Coupling	-	-	0.36	> 0.3
Offset (um)	-	< 5	< 5	< 10

Isolation between x-y planes is very important to achieve position resolution of 100 nm. The requirement of isolation < -30 dB was not easy without tuning mechanism for both with-dent and without-dent model. Using the tuning screws, the frequency can be adjusted accurately and the isolation could be controlled better than -50 dB. Tuning range of the cavity is as large as +/- 3 MHz.

Beam Test at ATF

One of the prototype BPMs was selected to be installed in the ATF extraction beamline for the test of sensitivity and isolation. Fig. 3 shows the signal detection circuit connected with BPM pickup and the beam signal from a single pass of a beam bunch. Real beam position was checked with two stripline BPMs installed upstream and downstream of the test cavity BPM. Beam intensity was 0.8 x 10^{10} e/bunch when measured with an integrating current transformer (ICT) installed at the end of the extraction beamline. Nominal ATF bunch length is 8 mm.

Sensitivity of the cavity BPM was measured to be 0.8 V/mm when the two port signals are combined as shown in Fig. 3. Isolation was better than 40 dB with real beam measurements. [6]

By comparing the correlation between output signals from two opposite ports of the cavity, the 100 nm resolution of position measurement was proved within the dynamic range of +/- 50 um. [7]

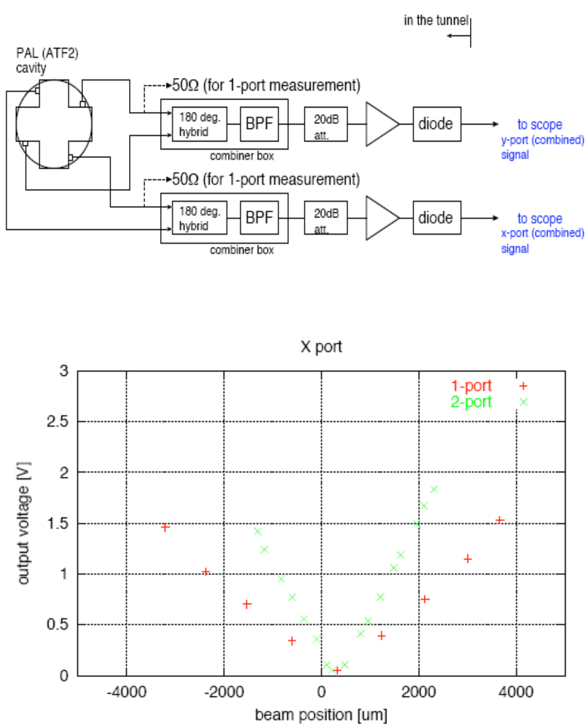


Figure 3: Signal detection circuit (top) and the sensitivity of cavity BPM (bottom) showing ~ 0.8 V/mm. Dashed lines are drawn for the guide over the 2-port data points (x). Quoted from Ref.[6].

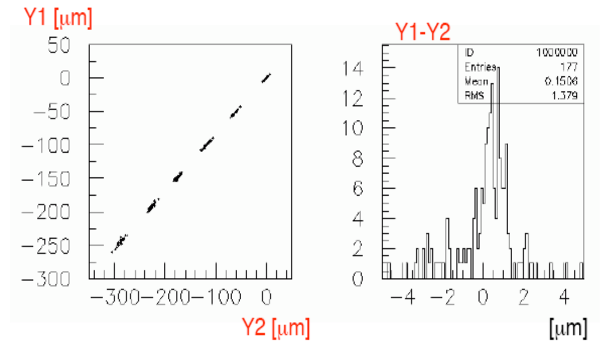


Figure 4: Comparison of two port signals (a), and the analysis of data shows 100nm rms resolution (b). Quoted from Ref. [7]

SUMMARY

Cavity BPMs are fabricated in PAL according to the KEK design. Errors in machining and brazing brought errors in the resonance frequency and isolation of the cavity. Resonance frequency of the cavity has increased slightly after the brazing. When the cavity is evacuated, the frequency further increases by 2 MHz. Four tuning screws positioned diagonally on the rim of the cavity could tune the cavity frequency and the x-y isolation well within the design parameters of the cavity. Overall design performance was proved through mechanical test, microwave test, and the beam test in the KEK-ATF.

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* Work supported by MOST, Korea, and KEK, Japan
# huang@postech.ac.kr

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