BEAM EXPERIMENT OF LOW Q CBPM PROTOTYPE FOR SXFEL*

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Abstract

To meet the high resolution beam position measurement requirement of micron or sub-micron for shanghai soft X-ray free electron laser (SXFEL) under construction, the cavity beam position monitor (CBPM) operating at C-band and the corresponding electronic has been designed by SINAP. In this paper, the design and optimize of the newly low Q cavity BPM is mentioned, the beam test was conducted on the Shanghai Deep ultraviolet free electron laser (SDUV-FEL) facility [1]. CBPM signal processors including broadband oscilloscope and home-made digital BPM processor have been used to evaluate the system performance as well. The beam experimental result, which matched with MAFIA simulation very well, will be presented and discussed in this paper.

INTRODUCTION

The Shanghai soft X-ray free electron laser (SXFEL) is a test facility for exploring key FEL schemes (EEHG/HGHG) and technologies, which adopt FEL frequency doubling of ultraviolet band seeded laser of 265 nm to achieve output wavelength of 9 nm, 100 fs pulse duration, 10 HZ repetition rate, and 100 MW peak power. The overall length of SXFEL is about 300 meters and the nominal electron beam energy of the linac is 0.84 GeV.

In order to ensure stable operation of SXFEL, they required beam position resolution of 1 um@0.5nC that the electron beam could overlap the generated photo beam stringently and pass through the entire undulator section together. Cavity BPM is the key beam instrument component only which could reach sub-micron or nanometer resolution. The quality factor (Q) is one of the most important parameters for the CBPM which is related to the output signal intensity and decay time. For the operation of the SXFEL, and considering the beam position diagnose of bunch-by-bunch, high Q cavity has a long decay time will cause signals overlapped and has strict performance requirements for the RF front end, so the CBPM in SXFEL adopts low Q scheme.

The low Q cavity BPM prototype designed for SXFEL has been fabricated and relevant electronics also have been developed. So as to conduct preliminary performance test, an array of two low Q cavity BPMs have been installed at the SDUV-FEL facility.

DESIGN OF THE CBPM

The low Q CBPM for SXFEL is designed by referencing the Spring-8 cavity BPM structure and experience [2]. For a cylindrical pill-box cavity, usually we use TM110 mode to measure the beam position and TM010 mode to remove the variation effect of bunch charge and normalize the amplitude from position cavity. Table1 show the pre-designed parameters of the low Q CBPM. The working frequency was chosen at 4.70 GHZ due to consider the vacuum pipe radius and to avoid the dark current from the accelerating system.

Table 1: Pre-designed parameters of the CBPM

	Position cavity	Reference cavity
Resonant frequency	4.70 GHZ	4.70 GHZ
Loaded Q factory	50	50
Number of ports	4(X:2, Y:2)	1

The three-dimension structure of the low Q CBPM is shown in Fig. 1. Based on various considerations and for get better performance, cavity material changes from copper to stainless steel of 304 and optimize the local structure of raw copper cavity [3,4].

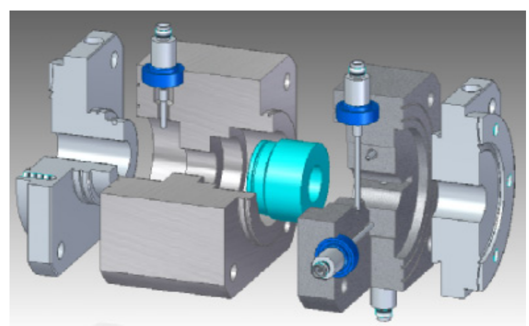

Figure 1: Three-dimension structure of the low Q CBPM.

For the TM110 cavity, using magnetic coupling structure, the TM110 mode signal is picked up through a coupling slot that is decoupled to the TM010 mode in order to minimize the export power.

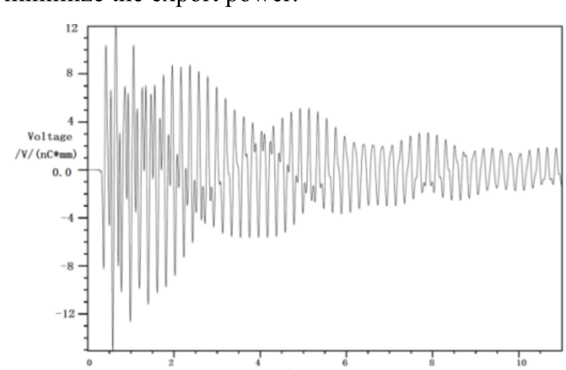

Figure 2: MAFIA simulation of the RF signals waveform.

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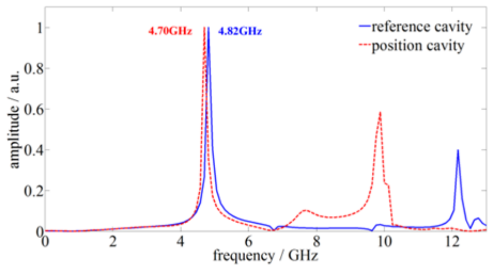

Figure 3: MAFIA simulation of the RF signals spectrum.

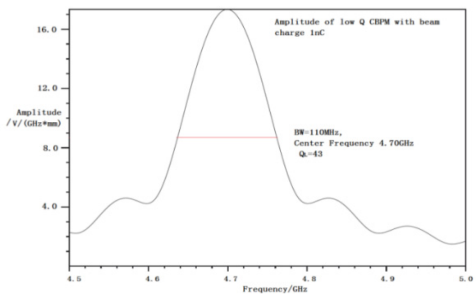

Figure 4: MAFIA simulation of the Q and central frequency.

The MAFIA simulation of the output RF signals waveform and spectrum of CBPM is shown in Fig. 2 and 3. The resonant frequency of reference cavity and position cavity is 4.82 GHZ and 4.70 GHZ respectively. The Q factor is about 43 and the central frequency by MAFIA simulation also be shown in Fig. 4.

Theoretically, if the bandwidth of electronics is 100 MHZ, the position sensitivity of output signal is about 2.4 V/mm*nC. Meanwhile, comparing the amplitude of thermal noise in this bandwidth is 0.009 mv, the theoretical position resolution of the best is about 4 nm@1nC for this CBPM design.

BEAM TEST

The beam test was conducted on the platform of SDUV. We evaluated the performance of the cavity BPM, measured the calibration factor and the Q factor. The detailed results were described in the following subsections.

Cavity Evaluation

The RF signal from the low Q CBPM in beam conditions can be used to evaluate the physical design.

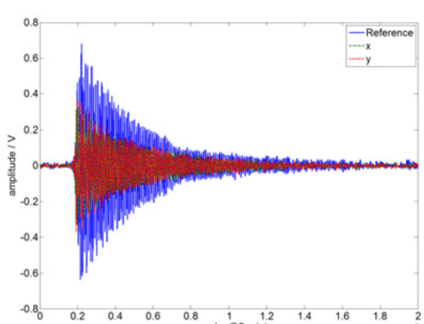

Figure 5: RF signals waveform of CBPM.

We use the broadband oscilloscope to process which can evaluate it directly. The CBPM output signal waveform with beam charge of 20 pC was shown in the Fig. 5. Fig. 6 and 7 show the two CBPM prototype spectrum of reference cavity and position cavity.

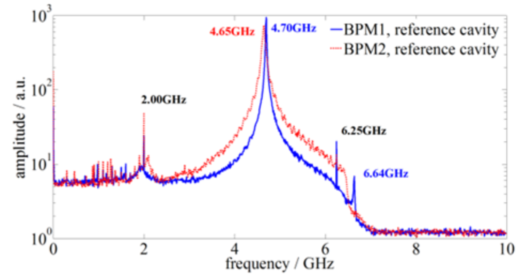

Figure 6: The spectrum of the reference cavity.

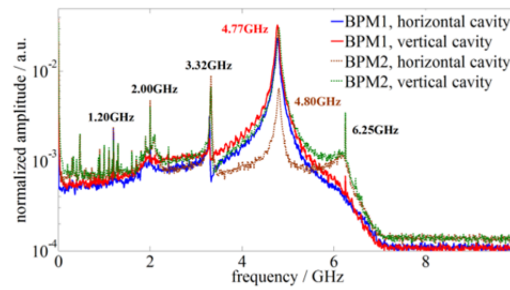

Figure 7: The spectrum of the position cavity.

The RF signal waveform accord with the theory well in time domain. Signal spectrum of reference cavity and position cavity is matched with MIFIA simulation basically.

Evaluation of the Q Factor

According to the data we got, the Q factor also can be evaluated. Fig. 8 show the Q values of the two CBPMs.

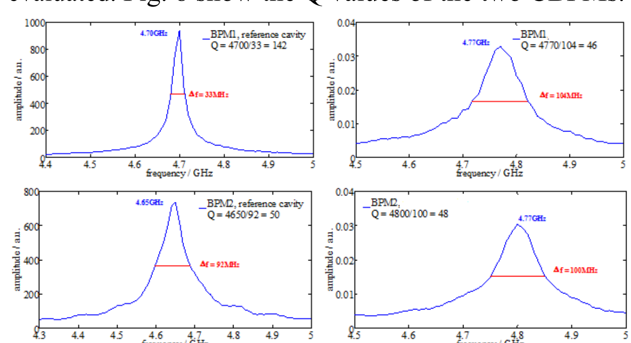

Figure 8: Q values of the two CBPMs ref cavity (left) and position cavity (right).

The Q value of the CBPM1 reference cavity and position cavity is 142 and 46, the discrepancy depends on the difference of the feed-through structure in fabricated. And the Q of the CBPM2 is 50 and 48 which is closed very well. In generally, the Q value is similar to the MAFIA simulation of 43.

Calibration

A two-dimensional motion platform was installed under the one of the cavity which can imitate the beam off-

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set on the horizontal and vertical directions. The diagram of the calibration measurement system is detailed in Fig.9.

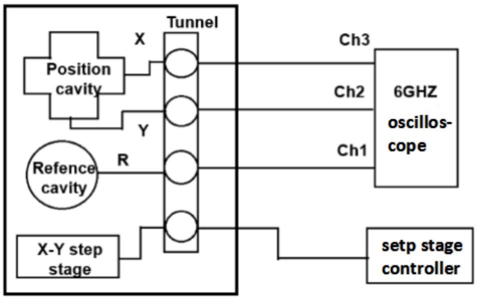


Figure 9: Diagram of the calibration system.

The platform from -4.0 mm to 4.0 mm with a step of 0.8mm on the horizontal axis and 0 mm to 0.9 mm with a step of 0.1 mm on the vertical axis. We use specified bandwidth integral area ratio in the frequency response curve to calculate the normalized position. The calibration factors of CBPM were shown in Fig. 10 which the data processing bandwidth is 30 MHZ. From the calibration, they matched well with each other.

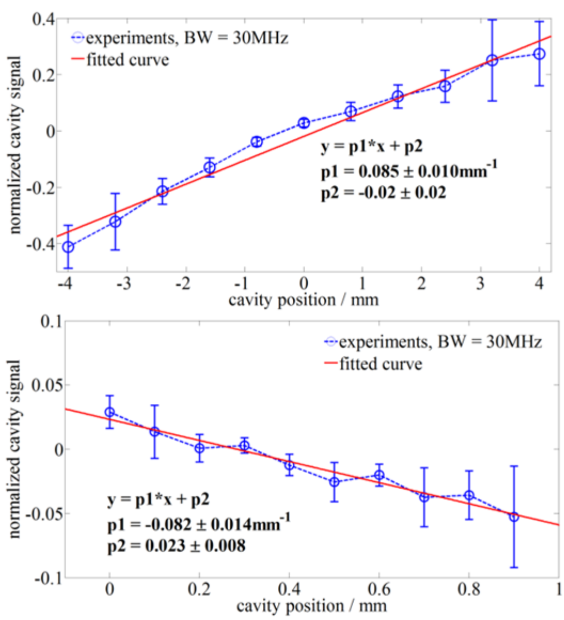
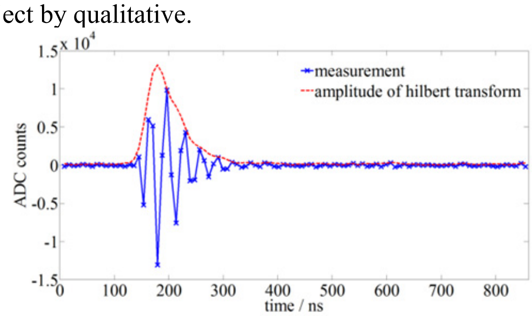


Figure 10: Calibration factors in horizontal (up) and vertical (down).

Home-made Digital BPM Processor

At last, we use home-made digital BPM processor instead of broadband oscilloscope to get the IF signals data, and evaluate whether it can meet the needs of the SXFEL project by qualitative.



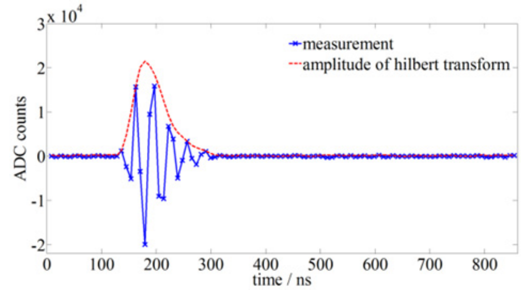


Figure 11: IF signals of reference cavity (up) and position cavity (down) sampled by home-made DBPM.

Figure 11 show the IF signals of reference cavity and position cavity sampled by home-made DBPM. The IF signals waveform are according with the expectations by qualitative analysis, more specific performance testing for home-made DBPM to be carried out in the latter.

Evaluated by PCA Method

In data analysis, we use a novel method of PCA to evaluate the performance of the low Q cavity BPM. Utilizing this method we determined the resonant frequency and Q factor of the reference and position cavity accurate, and found that the contribution of the disturbance signal coupled from the TM_{010} mode of the reference cavity was no more than 4 µm. More information and specific processes can be seen in [5].

CONCLUSION

We described the new designed low Q cavity BPM prototype for SXFEL which is conducted a preliminary test at the SDUV facility. Broadband oscilloscope was used to evaluate cavity performance that it matched with MIFIA simulation basically, verify the correctness of the physical and technological structure design of the CBPM. And we also use PCA method to evaluate CBPM performance. Since the limit of processed two sets of CBPM only, we can not get strict position resolution evaluation in this experiment, we will add a set of CBPM to make strict evaluation in the next test.

REFERENCES

[1] Z.T. Zhao *et al.*, "The shanghai high-gain harmonic generation DUV free-electron laser", Nuclear Instruments and Methods in Physics Research A 528 (2004) 591-594.

[2] H. Maesaka *et al.*, "Development of the RF cavity BPM of XFEL/Spring-8", in *Proc. DIPAC'09*, Basel, Switzerland, May 2009, paper MOPD07, pp. 56-58.

[3] Yuan Renxian *et al.*, "Design and test of SX-FEL cavity BPM", *Chinese physics C*, Vol.37, No.11, November, 2013.

[4] B.P. Wang *et al.*, "Development of Cavity Beam Position Monitor System", in *Proc. IPAC'13*, Shanghai, China, May 2013, paper MOPME051, pp. 586-588.

[5] Y.B. Leng *et al.*, "Cavity BPM Performance Online Evaluation using PCA Method", presented at IPAC'16, Busan, Korea, May 2016, paper MOPMB051, this conference.