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DEVELOPMENT OF AN X-BAND CBPM PROTOTYPE FOR SHINE*

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Abstract

SHINE (Shanghai High repetition rate XFEL aNd Extreme light facility) is a newly proposed high-repetition-rate X-ray FEL facility and will be used to generate brilliant X-rays between 0.4 and 0.25 keV. To guarantee the high performance of FEL light pulses, it is required to precisely monitoring the trajectory of the electron bunch. The position resolution of each bunch at the undulator section is required to be better than 200 nm at a bunch charge of 100 pC and 10 μm at a bunch charge of 10 pC. Since the cavity beam position monitor (CBPM) is widely used in FEL facilities for its unique high resolution and high sensitivity and the output signals of an ideal pillbox cavity are proportional to the resonant frequency, thus the X-band CBPM is preferred because it is expected to obtain better results at low bunch charge compared with the C-band CBPM. Therefore, an X-band CBPM prototype is also developed for SHINE. This paper will focus on the design and production process of the X-CBPM.

INTRODUCTION

SHINE is designed to become one of the most efficient and advanced free electron laser user facilities in the world and provide an ultra-powerful tool for cutting-edge research. The facility is composed of a superconducting linear accelerator, 3 underlines, 3 optical beam lines, and the first 10 experimental stations[1, 2]. The facility is designed to operate at a maximum repetition rate of 1 MHz and the beam energy is 8 GeV. The bunch charge is ranging from 10 pC to 300 pC. The pulse length is only 20 to 50 fs.

To build such an ultra-high performance FEL facility, stringent requirements are placed on the beam position monitor system so as to establish and maintain precise beam trajectory and prevent emittance growth. At the undulator section, the bunch position resolution is required to be better than 200 nm at a bunch charge of 100 pC and 10 um at 10 pC bunch charge. Since the cavity beam position monitors (CBPM) can couple high signal-to-noise ratio (SNR) RF signals for high-resolution bunch position detection and the reported position resolution can even reach nm-scale, thus the CBPM is utilized in this section. Generally, the CBPM can work at S-band, C-band and X-band. In this research, the X-band CBPM is selected for three reasons. Firstly, the X-band CBPM has a more compact structure. Secondly, the X-band CBPM is expected to extract the RF signals with better SNR. Thirdly, it could test the machining techniques of the manufacturers.

This paper will mainly introduce the design and cold test of the X-CBPM as well as the high-bandwidth feedthrough.

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REQUIREMENTS

As described in [3], the X-CBPM will operate at 11.483 GHz which has a 59.5 MHz deviation from the quadruple frequency of 2856 MHz. The bandwidth is ranging from 1.59 MHz to 3.18 MHz. Thus the decay time constant is ranging from 100 ns to 200 ns. In order to reduce the influence of beam jitter in the X/Y direction on the beam position measurement in the Y/X direction, the XY crosstalk is required to be smaller than -34 dB under a dynamic range of ±100 μm. The fundamental requirements of the X-CBPM have been summarized in Table 1.

Table 1: Requirements of X-CBPM

Parameters	Value	Unit
Frequency	11483	MHz
Decay time constant	100~200	ns
Qload	3611~7222	~
Bandwidth	1.59~3.18	MHz
XY crosstalk	<-34	dB
Crosstalk between Ref. and Pos. cavity	<-60	dB

DESIGN OF X-CBPM

The X-CBPM is composed of a position cavity and a reference cavity. The position cavity of X-CBPM is equipped with four rectangular waveguides and thus demands four high-bandwidth feedthroughs. The waveguides are mainly used to reject the TM010 mode and extract the TM110 mode. The structure of this cavity is shown in Fig. 1(a).

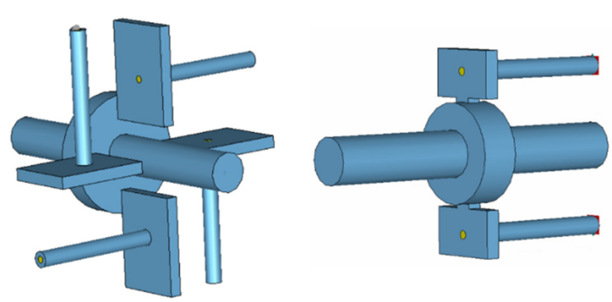

Figure 1: A 3-D view of X-CBPM vacuum parts: (a) position cavity; (b) reference cavity.

Unlike the previous CBPM reference cavity, the reference cavity of X-CBPM additionally contains two rectangular waveguides. This is mainly because of the limited space for installation of feedthrough. The diameters of the beam pipe and the reference cavity resonating at 11.483 GHz are 10 mm and 20 mm, respectively. Excluding the thickness of the cavity wall, the space left for installing feedthrough in the radial direction is less than

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4 mm. To solve this problem, a rectangular waveguide is added at both ends of the reference cavity, as shown in Fig. 1(b). The TM010 mode in the cylindrical cavity can enter the rectangular waveguide through magnetic coupling.

Using the computer simulation software (for example CST), the final CBPM model can be obtained through iterative optimization and calculation. The RF signals coupled from the X-CBPM are shown in Fig. 2. Among them, Fig. 2(a) and (c) show the waveforms generated in the reference cavity and position cavity, respectively; Fig. 2(b) and (d) present the frequency spectrum of the reference cavity and position cavity, respectively. The simulation results using CST can be summarized in Table 2. Both of the reference cavity and position cavity work at 11.483 GHz. The bandwidths of the reference cavity and position cavity are 1.81 MHz and 1.94 MHz, respectively.

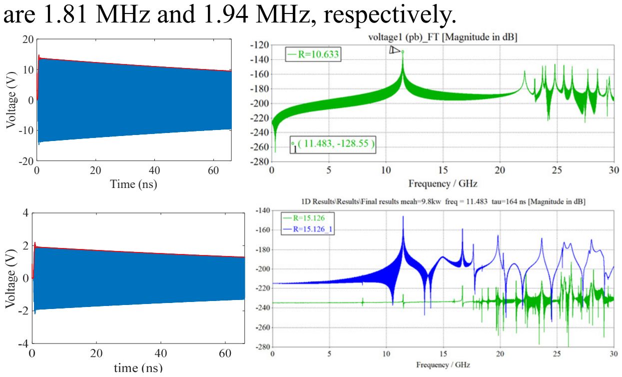

Figure 2: (a) The output signal waveform of reference cavity; (b) The frequency spectrum of reference cavity; (c) the output signal waveform of position cavity; (d) the frequency spectrum of position cavity.

Table 2: Simulation Results of X-CBPM

Parameters	Reference cavity	Position cavity
Frequency/GHz	11.483	11.483
Decay time constant/ns	164	176
Qload	6344	5919
Bandwidth/MHz	1.81	1.94
Sensitivity/(V/nC)	14	2@1 mm

TEST OF X-CBPM

In order to understand the characteristic of the X-CBPM, multiple tests have been performed during the production process with a broadband network analyzer. The X-CBPM has been manufactured last year, as shown in Fig. 3. The whole length of the X-CBPM is 144 mm. The distance between the reference cavity and position cavity is more than 60 mm to improve the isolation between the two cavities.

The first cold test results have been measured with a NA, as shown in Fig. 4. There are several unexpected modes that occurred in the frequency response of the reference cavity and position cavity. During the second test, we made some improvements to reduce the gap between the cavity parts by adding few circular rings between the gaps. The feedthroughs are further fixed. Moreover, the reference cavity and position cavity are tested seperatly, as shown in Fig. 5.

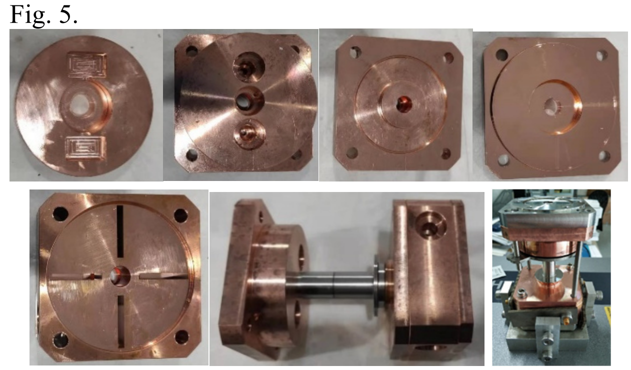

Figure 3: The photos of X-CBPM.

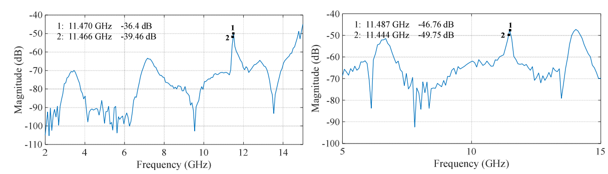

Figure 4: The first cold test result: (a) position cavity; (b) reference cavity.

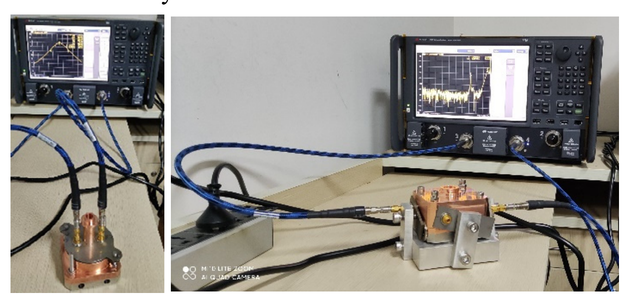

Figure 5: Photos of X-CBPM second test.

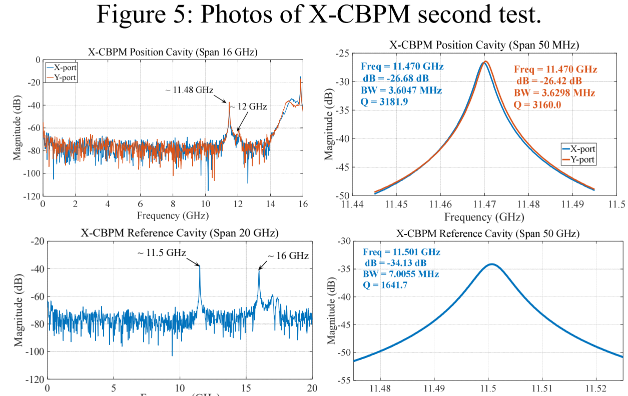

Figure 6: Frequency response of the second cold test: (a) Position cavity (span=15 GHz); (b) Position cavity (span=50 MHz); (c) Reference cavity (span=20 GHz); (d) Reference cavity (span=50 MHz).

The second cold test results are presented in Fig. 6. It is apparent that the frequency response of the position cavity and reference cavity in Fig. 6.(a) and (c) is quite different from that in Fig. 5. The unexpected modes in Fig. 5 have disappeared in Fig. 6. The tested frequency responses of the position cavity and reference cavity are almost consistent with simulation results. The measured frequencies

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of the position cavity and reference cavity are 11.470 GHz and 11.501 GHz, respectively. The measured bandwidths for position and reference cavity are 3.6 MHz and 7.0 MHz. However, there is an unanticipated mode operating at 12 GHz near the TM110 mode of the position cavity. The frequency response of the mode is related to the pressure on the cavity. Figure 7 shows two different frequency response under different pressure on the position cavity.

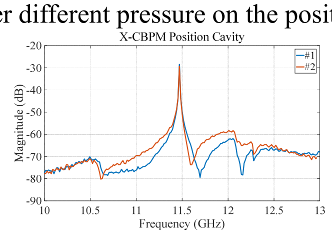

Figure 7: Frequency response under different pressure on the position cavity.

Finally, the physical photo of the cavity after brazing and argon arc welding is shown in Fig. 8. The cold test results are presented in Fig. 9. Among them, Fig. 9(a) shows the frequency response of reference cavity, position cavity-X, and position cavity-Y, respectively. The frequency response of the reference cavity is consistent with that in Fig. 6. The frequency response of the position cavity is slightly different from the second test result. The 12-GHz-mode has disappeared this time. The cold test results show that the frequency of the reference cavity is 11.506 GHz, which is 23 MHz larger than the simulation result of 11.483 GHz. The position cavity-X and position cavity-Y are 11.485 GHz and 11.486 GHz, respectively, which are quite close to the simulation frequency of 11.483 GHz. The measured bandwidth of the reference cavity is completely consistent with the simulation result, but the measured bandwidths of the position cavity-X and position cavity-Y are 0.6 and 0.4 MHz larger than the simulation result. The measured maximal XY crosstalk is -44 dB which can still satisfy the requirement. The final test results have summarized in Table 3.

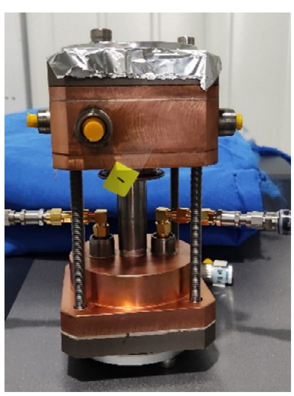

Figure 8: The physical photo of the X-CBPM.

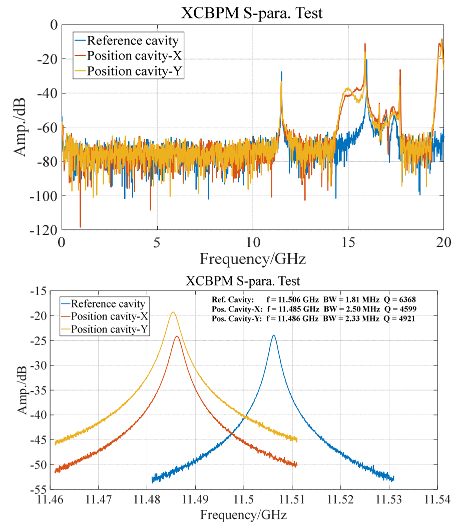

Figure 9: (a) Frequency response of X-CBPM (span=20 GHz); (b) Frequency response of X-CBPM (span=50 MHz).

Table 3: Final Cold Test Results of X-CBPM

Parameters	Ref.	Pos-X	Pos-Y
Frequency/GHz	11.506	11.485	11.486
Decay time constant/ns	176	127	138
Qload	6368	4599	4921
Bandwidth/MHz	1.81	2.5	2.3
XY crosstalk/dB	~	-44	

CONCLUSION

An X band cavity BPM prototype has been successfully developed. The results of multiple tests show good suppression of these unexpected modes so that there is no significant interference on the measurement of the dipole mode. An important experience is that reducing the cavity gap can help obtain effective cold test results before welding.

Plans are being made to construct two additional X-CBPM and test them in SXFEL as soon as possible. The important resolution can be obtained under beam conditions in the near future.

REFERENCES

[1] Feng. C. and Deng. H., "Review of fully coherent free-electron lasers", *Nucl. Sci. Tech.*, vol. 29, p. 160, 2018. doi:10.1007/s41365-018-0490-1

[2] Z. Zhu, Z. T. Zhao, D. Wang, Z. H. Yang, and L. Yin, "SCLF: An 8-GeV CW SCRF Linac-Based X-Ray FEL Facility in Shanghai", in *Proc. 38th Int. Free Electron Laser Conf. (FEL'17)*, Santa Fe, NM, USA, Aug. 2017, pp. 182-184. doi:10.18429/JACoW-FEL2017-MOP055

[3] S. S. Cao, R. Jiang, Y. B. Leng, and R. X. Yuan, "Design and Test of CBPM Prototypes for SHINE", in *Proc. 9th Int. Beam Instrumentation Conf. (IBIC'20)*, Santos, Brazil, Sep. 2020, pp. 124-127. doi:10.18429/JACoW-IBIC2020-WEPP13