DEVELOPMENT OF CAVITY BEAM POSITION MONITOR SYSTEM*

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Abstract

Requirement of position resolution of Shanghai soft X-ray free electron laser (SXFEL) facility is less than 1 μm in the undulator sections. Cavity BPM system, feasible in obtaining sub micron position resolution, has been developed to achieve the goal. The design of high Q and low Q cavities was accomplished and prototypes were fabricated. The relevant dedicated electronic, which could cover the two types of cavity BPMs, also have been developed. Fast fourier transform (FFT) and digital down converted based algorithms were implemented. The beam test of the whole system will be conducted on the Shanghai deep ultraviolet (SDUV) FEL facility. The cavity design, electronic architecture, achieved bunch test performance would be presented

INTRODUCTION

Shanghai deep ultraviolet FEL [1](SDUV-FEL) facility operating in the high gain harmonic generation is a scaled demonstrator system for the soft X-ray FEL project The requirement of beam position resolution in shanghai soft X ray FEL project is superior to 1 μm which is the goal of CBPM signal processing system.

The High-Q cavity BPM was designed with 5.712GHz resonant frequency [2] and relevant beam test has been conducted on SDUV FEL, as the problem of RF front end and beam jitter and dark current, the resolution was not acquired, but some Monte Carlo based simulation results have been acquired [3]. A new low Q cavity BPM was also designed and fabricated with 4.65GHz resonant frequency as vacuum pipe radius and avoiding the dark current from accelerating RF system.

In the process of CBPM development, a dedicated high precision test platform was needed for CBPM bunch test. As the requirement of better than 1 μm position resolution, step precision of platform should reach the sub-micron level. We employ commercial products to develop the test platform. Also, a new RF front end and relevant signal processing algorithm were designed and implemented. Bench test of the whole system performance was conducted on the high accuracy platform.

DESIGN of LOW-Q CBPM STRUCTURE

The low-Q CBPM employs the structure of cylindrical pill-box. When electron bunch transits through the cavity along z-axis, a series of TM modes will be excited. Bunch lost energy on these modes, among which, monopole. TM010 mode got the most lost energy as its amplitude of E field on z-axis is largest. And dipole TM110 mode got the least energy. Its amplitude of E field on z-axis is zero when bunch is near to z-axis. It is very important to design an appropriate coupling structure which can export the TM_{110} mode very well and damp most of the power from TM_{010} mode at the same time. The coupling structure is designed as a slot along z-axis, and the energy of TM_{011} mode is exported as magnetic field coupling. The structure of the CBPM is designed as Fig.1.

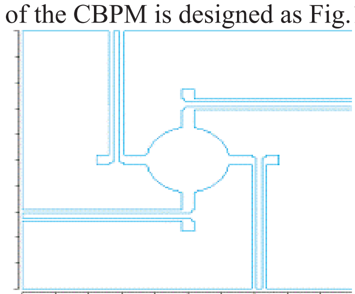

Figure 1: Structure of prototype CBPM.

The amplitude and its spectrum of the output signal are simulated from Mafia and seen as Fig.2 when $\Delta x = 0.5mm$. From the spectrum in Fig.3, the TM_{010} mode is damped about 110dB.

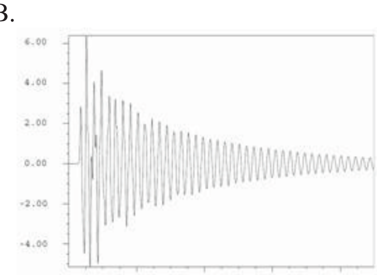

Figure 2: output of CBPM in simulation with 1nC charge and 0.5mm position offset.

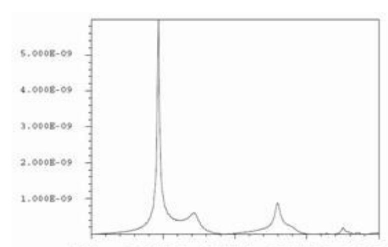

Figure 3: Spectrum of CBPM in simulation with 1nC charge and 0.5mm position offset.

COLD TEST PLATFORM OF CBPM

We employ commercial products to develop a test platform [4]. Also software of instrument control and data acquisition was implemented by visual instrument

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technique. Hardware of test platform consists of high precision positioning platform, related controller, DAQ card, computer and connector. Fig.4 shows the architecture diagram of the whole system.

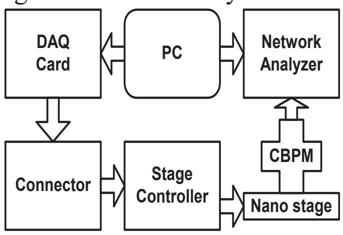

Figure 4: Diagram of CBPM measurement system.

In the process of CBPM bench test, we employ antenna to simulate the beam field. CBPM was fixed on high precision platform. First let the platform move from 0 to 200μm with step of 0.2μm to simulate beam offset. At every positioning, we acquired the signal intensity of CBPM output by network analyzer, in which we measured S21 parameters of linear format and regarded its peak magnitude as output signal of cavity. So we could get 1000 data samples. And then we fit the 1000 data samples linearly to get the linear factor, by which we also get theoretical positions of every step of platform. After that we got sample differences by the theoretical positions, from which the real position was subtracted correspondingly. Finally the standard deviation of the sample differences was regarded as the sensitivity of the whole test platform. The procedure of data processing was described in Eq. 1 and Eq. 2[5].

$$\delta = \langle \Delta x \rangle = \sqrt{\langle \Delta x^2 \rangle} \tag{1}$$

$$\langle \Delta x^2 \rangle = \frac{\sum_{i=1}^{n} (V_i^a - V_i^m)^2}{k^2 n} \tag{2}$$

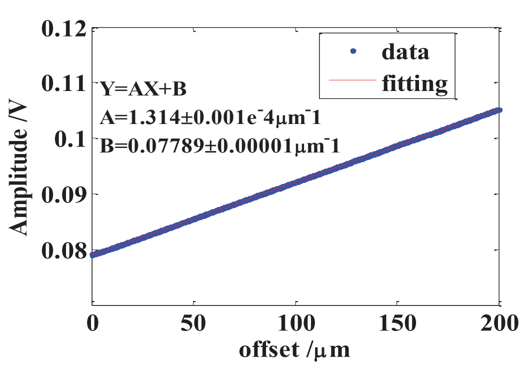

Figure 5: Linear fitting of 1000 samples.

Where V_i^a is theoretical position signal, V_i^m is real position signal, k is the linear fitting factor. Fig. 5 is the fitting of 1000 samples and Fig. 6 is the histogram of sample deviation between theoretical position and practical position. The results show that the positioning precision of platform reaches 0.225μm.

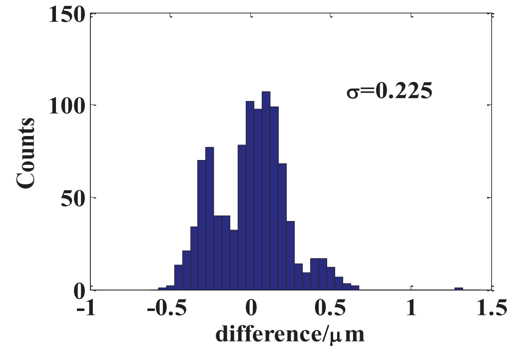

Figure 6: Histogram of sample deviation between theoretical position and real position.

ELECTRONICS

The RF signal of CBPM would be converted to IF and then digitized by the above-mentioned commercial board with up to 160MHz sampling rate. The schematic is detailed in figure 6.

The RF signals from CBPM are fed into the first BPF (band pass filter) with the following characteristics: central frequency 4.7GHz (5.712GHz), bandwidth 100MHz and stop-band attenuation 60dB to suppress the other harmonics, and then into a low noise amplifier (LNA) with 45dB gain, by which the broader dynamic range can be acquired. A mixer with 3.7GHz-7GHz input bandwidth will process the conversion from RF to IF signal, but it needs the high LO (local oscillator) power. In the channel of LO, an amplifier, with high output power of 1-dB compression point, is added before the power divider to meet the LO input of the mixer. In the IF section, a 32MHz-bandwidth (11MHz-bandwidth) LPF was used to remove the high order harmonics generated from the mixer. An IF amplifier accomplishes the last gain adjusting to fulfil the following input requirement of ADCs. The last LPF was used as anti-aliasing filter to suppress other amplified harmonics.

The linearity error of the three channels is less than 2% when the input power is more than -80dBm. Furthermore, the noise level is less than -90dBm. The test results were shown in Fig.7.

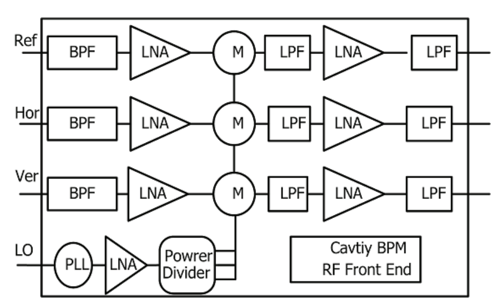

Figure 7: Schematic of RF front end.

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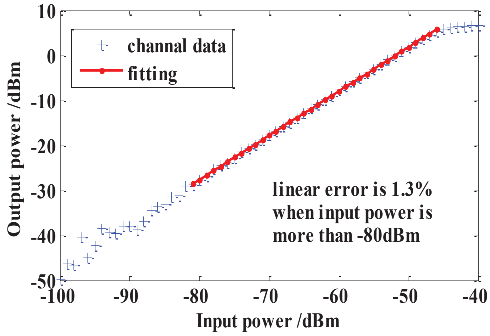

Figure 8: Gain line test of RF front end.

SYSTEMATIC PERFORMANCE

For the systematic performance evaluation, we employ DDC and FFT algorithm to process signal of CBPM[6].In the procedure of test, the RF signal of -16 dBm was input to the antenna. And then we moved the platform from 0μm to 100μm with 2μm stepping. At every positioning, we acquired 100 samples among which every sample got 256 sampling points according to simulation results in [3].

Owing to much run time of fitting algorithm and difficulty of implementation on an FPGA device, we decided to adopt DDC and FFT algorithm respectively to demodulate the calibration scale factor and evaluate the performance of position resolution. Also the DDC algorithm, which could be applied in the high Q or low Q CBPM system, was chose to be implemented on the FPGA device. Fig.9 and Fig.10 show the resolution of applying DDC and FFT algorithms respectively. Fig.11 shows the result of applying FPGA in signal processing.

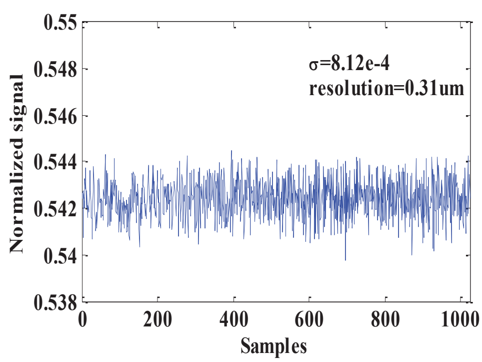

Figure 9: Position resolution by using DDC.

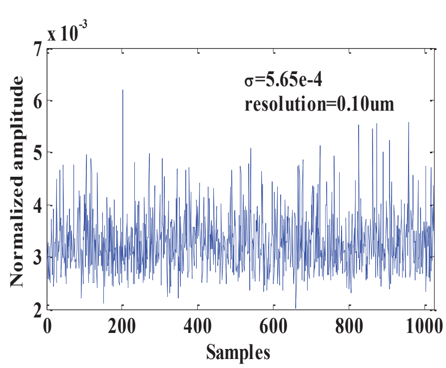

Figure 10: Position resolution by using FFT.

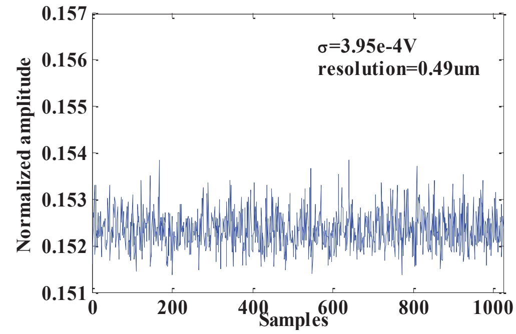

Figure 11: Position resolution by using FPGA.

CONCLUSION

At present, the low-Q CBPM and the whole CBPM signal processing system were accomplished. in the direct cold test of CBPM by using network analyzer, we got the resolution of0.225μm.. In the test of the whole system including CBPM and dedicated electronics, we got the position resolution of 0.31μm using DDC algorithm and that of 0.10μm in FFT algorithm on the condition that input power is -16 dBm. It meets the requirement of beam position diagnostic in shanghai soft X ray FEL facility. Also the preliminary FPGA algorithm was implemented and the bunch test has been done. We got the a little worse resolution than that of digital algorithm, but it also meets the requirement of Shanghai soft X ray FEL facility. But since experiment condition did not work, beam test had not been conducted yet. So we look forward to the beam test of the whole CBPM system in the future.

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