STUDY OF THE SIGNAL PROCESSING SYSTEM FOR CAVITY BEAM POSITION MONITOR

B.P. Wang*, Y.B. Leng†, N. Zhang, L.Y. Yu, W. M. Zhou, R.X. Yuan, Z.C. Chen
SSRF, SINAP, Shanghai, China

Abstract

A prototype of cavity beam position monitor (CBPM), with resonant frequency of 5712MHz [1] and high Q, has been installed in the Shanghai deep ultraviolet free-electron laser source (SDUV-FEL) facility. A plug & play CBPM signal processor based on broadband oscilloscope embedded IOC (input output controller) and FFT (fast Fourier transform) technique has been developed to do quick evaluation of prototype [2]. According to the evaluation results, a series of simulation using Monte Carlo simulation method, have been carried out as a guideline for the design of dedicated CBPM signal processing system.

An RF front end for a prototype of CBPM with resonant frequency of 4700MHz and low Q using the microwave devices is developed and relevant digital signal process algorithms are implemented in MATLAB. Systematic test in lab has been done to evaluate the performance. We got a resolution of 2.8 μm when the continuous sine input signal is 6dBm.

INTRODUCTION

The free electron laser (FEL) operating in high gain harmonic generation (HGHG) or self-amplified spontaneous emission (SASE) regime required such high beam position resolution that the electron beam could overlap the generated photon beam stringently and pass through the entire undulator section together. CBPM, which can achieve nano scale resolution as reported [3][4][5], is important and indispensable for the free electron laser (FEL) facility. The Shanghai deep ultraviolet free-electron laser source (SDUV-FEL) facility is operating for cascaded HGHG FEL [6]. According to the relevant references, two types of CBPM with high or low Q, which has something to do with signal intensity, regression time and bandwidth, were developed and used in FEL facilities. For different CBPMs, the different signal process system would be designed.

A beam test based on broadband oscilloscope embedded IOC has been done for high-quality-factor CBPM with resonant frequency of 5712MHz. The typical algorithms, such as fitting and digital down convert (DDC)[7], are used in most CBPM signal process systems. We decided to use the FFT technique to implement the beam position measurement. The optimal data length for the FFT technique has been simulated by using signal of beam test. Right now, a prototype of CBPM, not in vacuum, was newly manufactured with 4.7GHz resonant frequency and low Q. And the corresponding CBPM electronics were developed. As we would evaluate performance of two types of CBPM and choose one of them to be used in the future FEL facility, the electronics cover the two prototypes.

*wbplll@sinap.ac.cn
†lengyongbin@sinap.ac.cn

SYSTEM SETUP

The CBPM electronics consist of a dedicated RF (radio frequency) front end and a commercial data acquisition board.

RF front end based on the RF receiver architecture is absolutely essential to convert the RF signals to intermediate frequency (IF). Table 1 shows the detail about the selection in our system design.

Table 1: Parameters of CBPMs and RF Front End

	Prototype 1	Prototype 2
Resonant freq.	5.712GHz	4.700GHz
Loaded Q	~5600	~60
Signal intensity	Weak	Strong
Decay time	~156 ns	~2 ns
Output SNR	Low	High
BPF stop band	>70dB	A little loose
LNA gain	High	Low
IF	20MHz	10 or 20MHz
Bandwidth	10~20MHz	<10MHz or less
Sample rate	160MHz	160MHz

For a high Q cavity, output signal with low SNR and narrow bandwidth could be processed by fitting algorithm, DDC and FFT technique. RF front end and digital filter of particularly narrow bandwidth would improve the SNR.

For a low Q cavity, the SNR of CBPM output is particularly high and the bandwidth is very wide. The performance requirement for RF front end is looser than that of low Q cavity. There are not enough samples for FFT technique. But analog IQ modulation and DDC algorithm work well for it. For the analog modulation, consistency of the amplitude and the phase is required rigorously. So we decide to use the latter. Time response of IF signal must be extended by the tightest bandwidth of RF front end and then the digital filter can improve the SNR further. The tightest bandwidth of system, less than that of the output, also made the amplitude weak, so we

ISBN 978-3-95450-115-1

must choose the optimal performance by making a balance between the two parameters.

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. In the process of the test, a 30dB-fixed attenuator was used to limit the peak power. We input the power from -80dBm to 18dBm from a signal generator to a power divider to generate three-channel RF signals, which then were utilized as the RF front end input power. The output of the RF front end would be sampled by a commercial board (ICS1554A-002) with 160MHz sampling rate. Fig.1 shows the gain line test results.

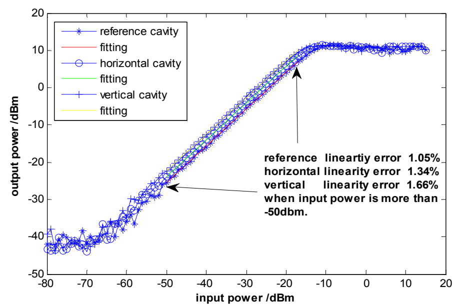

Figure 1: Gain line test of RF front end.

The linearity error of the three channels is less than 2% when the input power is more than -50dBm. Furthermore, the noise level is less than -60dBm.

HIGH Q PROTOTYPE

Beam Test

A beam test has been done on the platform of SDUV. In the process of the test we used the broadband oscilloscope embedded IOC to evaluate the CBPM directly. A two -dimensional motion platform, installed under the cavity, was used to imitate the beam offset from 0 mm to 5 mm with a step of 0.5mm. The vertical signals in Fig.2 were sampled in the presence of the beam charge less than 100pC without gain adjusted. The signals at 3.5mm offset were shown in the Fig.3.

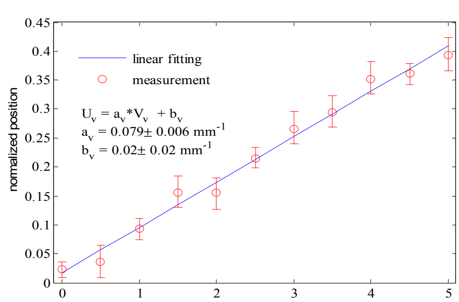

Figure 2: Calibration factors of CBPM [2].

Also, with the RF front end and the commercial board, IF signals were sampled. But as a result of the gain problem at RF front end, intensity of all the signals is not up to the best performance of the ADCs. Fig.4 shows the output signal after RF front end at 5 mm beam offset. The calibration factors were shown in Fig.5.

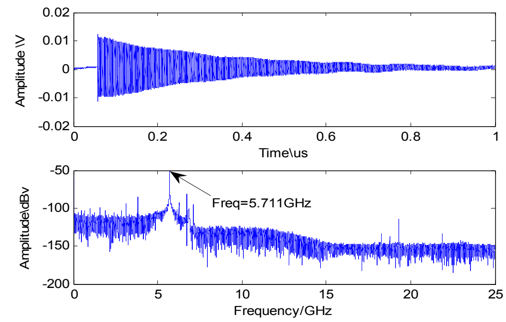

Figure 3: CBPM output at 3.5mm beam offset.

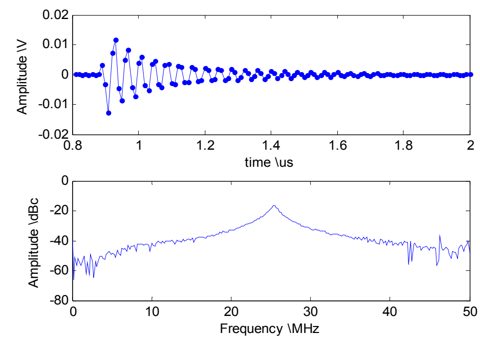

Figure 4: CBPM output signal at beam offset 5mm.

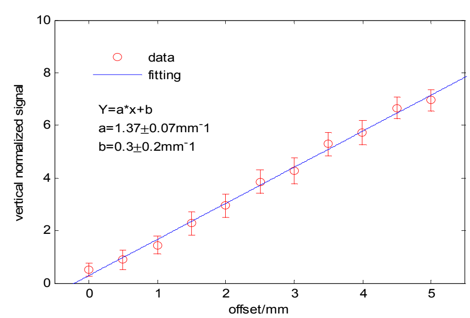

Figure 5: Calibration factors of CBPM.

From the figures mentioned above, we could know resonant frequency of CBPM after being brazed is consonant with theoretical design.

Simulation

DSP could be accomplished in time or frequency domain, and the traditional algorithms for CBPM have been implemented in time domain. However, algorithm in frequency domain is also feasible. FFT technique was used to complete the signal process in our signal process system of CBPM.

In FFT technique, the length of samples is so important for position resolution that we, based on Monte Carlo simulation method, simulated the optimal length for IF samples. The result was shown in Fig.6, from that we could directly get the optimal length for sampling IF signals is 256.

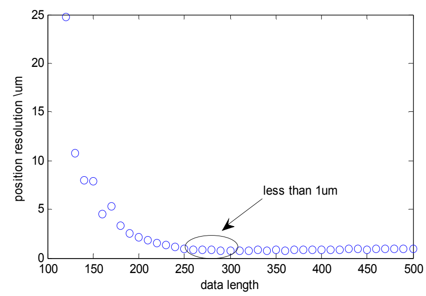

Figure 6: Data length simulation in IF sampling.

LOW Q PROTOTYPE

The newly manufactured CBPM with 4.7GHz resonant frequency and low Q has been tested in lab. In our signal process electronics, an RF front end and a commercial data acquisition board are included to implement IF signal sampling and DDC signal process.

EVALUATION OF ELECTRONICS

In the process of performance evaluation, continuous signals of 6dBm were input to the cavity, and then output signals were transferred to the RF front end and then to the commercial board in order. Platform beneath the cavity was moved from 0 μm to 200 μm with 5 μm stepping.

We have implemented the signal process in MATLAB. The calibration factors were shown in Fig.7.

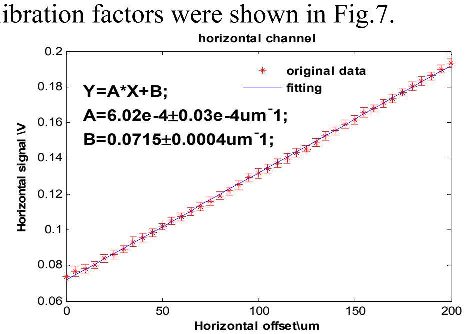

Figure 7: calibration factors.

The resolution test was done at a big offset so as to make ADCs work well. 1024 samples were shown in Fig.8 and position resolution of 2.8 μm was acquired.

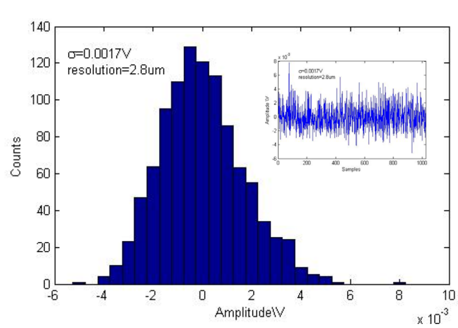

Figure 8: Samples at a certain offset.

The thermal noise of the electronics contributes to the position resolution of the low Q CBPM. Fig. 9 shows the noise level of the RF front end using DDC algorithm without any input signals.

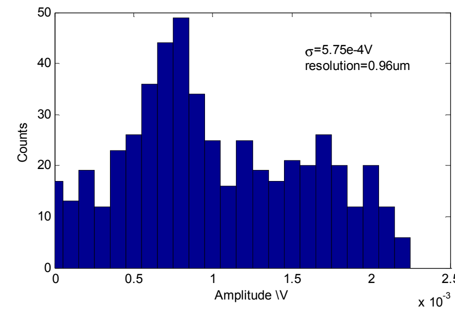

Figure 9: Noise level of RF front end.

From the above figures, in our bunch test, noise of the RF front end is an effect of resolution but not main effect. The deterioration of the SNR in the system bandwidth is due to the manufacture error of the antenna used in the bunch test that would excite other resonant modes.

CONCLUSION

We have discussed signal process methods for two types of CBPMs and designed the whole signal process system. Relevant algorithms have been implemented. The whole evaluation of performance has been done in bench test. We got 2.8 μm resolution, not qualifying our design goal of less than 1 μm, for low Q CBPM on the condition that the input power is just 6 dBm. So there is more work to be done to optimize system performance and we look forward to beam test in the future.

REFERENCE

[1] Chun Jianhua et al. RF Measurements of a C-band Cavity Beam position monitor. Chinese Physics C (HEP&NP), Vol.32, No.5, May, 2008.

[2] Zhang Ning et al. An on-line data acquisition system of oscilloscope -embedded input / output controller for cavity BPM measurement. Nuclear Science and Techniques 22 (2011) 321–325

[3] S.T.Boogert et al. Cavity Beam Position Monitor System For ATF2. Proceedings of IPAC'10, Kyoto, Japan

[4] H. Maesaka et al. Development of the RF cavity BPM of XFEL/SPRING-8. Proceedings of DIPAC09, Basel, Switzerland.

[5] S.Smith et al. LCLS cavity beam position monitors. Proceedings of DIPAC09, Basel, Switzerland.

[6] 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.

[7] Sean Walston et al. Performance of a High Resolution Cavity Beam Position Monitor System. Nuclear Instruments and Methods in Physics Research A 578 (2007) 1–22.

ISBN 978-3-95450-115-1