BEAM ARRIVAL TIME ANALYSIS BASED ON CBPM AT DCLS

S. S. Cao†, N. Zhang, J.Chen, L.W.Lai, Y. B. Leng#
SSRF, SINAP, Shanghai, China

Abstract

Free electron lasers (FEL) with high brightness, ultrafast laser pulses is an ideal light source for applications in the frontier researches of physics, chemistry, biology, energy and materials sciences. Such high brightness requests high precision control of beam arrival time (BAT). Thus a preliminary research based on the reference cavities of cavity beam position monitors (RCBPM) located at the undulator section of Dalian coherent light source (DCLS) was conducted. The temporal resolutions were calculated by comparing the phase of beam induced signals from two RCBPMs and using fitting algorithm. In this paper, we presented the scheme of the BAT research, analyzed the simulation and experiment results to predict the possible temporal resolution, evaluated the consistency and stability of BAT and obtained a temporal resolution of 32 fs.

INTRODUCTION

DCLS, as the first FEL user facility in the world, is a tunable coherent light source based on the high gain harmonic generation (HGHG) techniques operating exclusively in the EUV wavelength region. It is convinced that DCLS could be an ideal facility to supply stable beam and high performance equipment for the research. Figure 1 shows the layout of DCLS [1]. The main parameters of DCLS could be found in Table 1 [2].

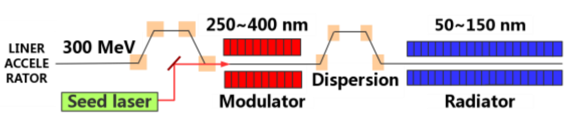

Figure 1: Layout of DCLS.

Table 1: Main Parameters of DCLS

Parameter	Value
Beam energy	300 MeV
Energy spread	0.2 %
Bunch charge	500 pC
Bunch length	2 ps
Peak current	250 A
emittance	2 mm·mrad
Wavelength	50 – 150 nm
Pulse energy	0.1 – 1 mJ
Pulse duration (FWHM)	100 fs / 1 ps
Rep Rate	50 Hz

The RCBPM utilizes the high intensity of TM010 monopole mode whose output signal amplitude only depends on beam charge while is irrelevant to beam offset. Thus it could be used as beam arrival time monitors (BAMs) to attain femtoseconds temporal measurement resolution. Figure 2 shows the prototype of CBPMs a DCLS. Table 2 shows the basic parameters of RCBPM we used. Figure 3 shows the layout of CBPMs in undulator section.

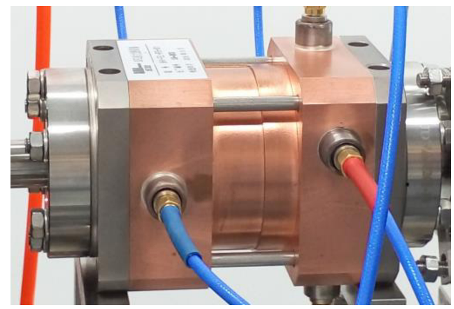

Figure 2: Prototype of CBPMs at DCLS

Table 2: Parameters of Reference Cavities

Parameter	Value
frequency	4.695
Loaded quality factor	2300

In this paper, we calculated the resolution of RF signal and IF signal, evaluated the BAT stability, then highlighted the impact of signal-to-noise-ratio (SNR) on the temporal resolution, compared the difference of the resolution between simulation results and experiment results. The simulation used ideal exponential decaying IF signal superimposed by different noise as the input signal and utilized two sampling rate to digitize the IF signal, which analyzed the relationship between SNR, sampling rate and temporal resolution.

SIMULATION

To investigate the impact of noise on time resolution, a simulation based on MATLAB was carried out. The initial signal was:

$$y_{in}(t) = A_s \sin(wt+\varphi_0) * e^{-t/\tau} .$$

Before sampling, a random noise had to be superimposed on the above signal. Moreover, the ratio of maximum noise signal amplitude to the input signal amplitude is in the range of 1 to 10e5. To be mentioned, the above noise signal includes the subsequent noise signal introduced during sampling process. After digitization, the time resolution can be calculated using fitting algorithm.

* Work supported by National Natural Science Foundation of China (No.11575282)
† caoshanshan1992@sinap.ac.cn # lengyongbin@sinap.ac.cn

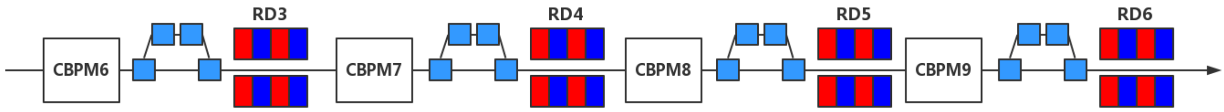

Figure 3: Layout of CBPMs in undulator section

In Fig. 4, the simulation results show that the higher SNR and sampling rate resulted in a smaller time jitter, which can be used to predict the lowest limit for given resolution.

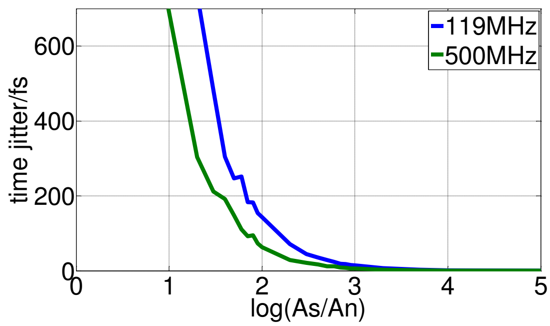

Figure 4: Time jitter in different SNR and sampling rate.

SIGNAL PROCESS

To obtain the data of the beam induced RF signal coupled out from the antennas, an oscilloscope and a RF front-end electronics system were applied. The former can digitize RF signal directly at a constant sampling rate of 25 GHz. We collected the RF data from four CBPMs, which is served to evaluate the stability of beam arrival time resolution. The latter consists of a local oscillator (LO) that is mainly used to produce a certain frequency reference signal, a low noise amplifier (LNA) to amplify the reference signal to meet the input requirement of subsequent device, a down-conversion mixer to obtain an intermediate frequency (IF) signal while keeping the information of preserved signal, and a 12 bit Analog-to-Digital Converter (ADC). The ADC is used for IF signal sampling with 119 MHz sampling rate. For completeness, the schematic diagram of the signal process is shown in Fig. 5 [3].

When the digital RF signal and IF signal were obtained, MATLAB was used to process these data. The core method is comparing the phase difference of two cavities. Considering the phases of cavity #a and cavity #b are:

$$\phi_a = \phi_0 + \phi_{noise0}$$
$$\phi_b = \phi_1 + \phi_{noise1} \, .$$

Assuming the flight time from cavity #a to cavity #b and phase noise are constant, thus the RMS value of phase difference can be seen as beam arrival time resolution.

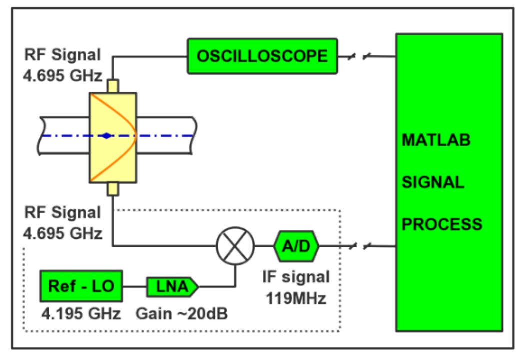

Figure 5: Signal process schematic diagram

RF Signal Analysis

The temporal (phase) measurement resolution of CBPM system was checked by two RCBPMs. Figure 6 shows the RF signal of RCBPM#6. Figure 7 shows the correlation plot of the measured phases from two adjacent BPMs.

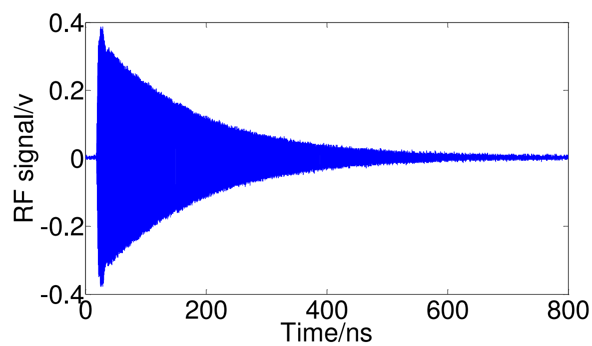

Figure 6: RF signal of CBPM #6

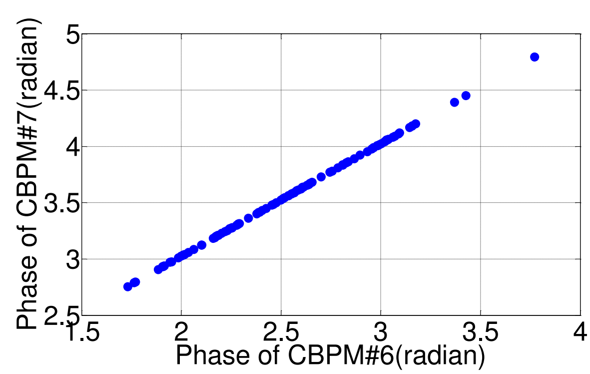

Figure 7: A correlation plot of the measured phase

Using MATLAB, the RMS value of phase deviation is 0.0019 radian at 4.695 GHz, which corresponds to 46 fs. This value is larger than that of president experiment results from other laboratories [4, 5]. To evaluate the stability of BFT, the other two CBPMs were also measured. As shown in Fig. 8, it is found that although the resolution values of non-adjacent cavity varies greatly, the adjacent RCBPMs are much more stable, fluctuating from 41 fs to 46 fs and the difference is only 5 fs.

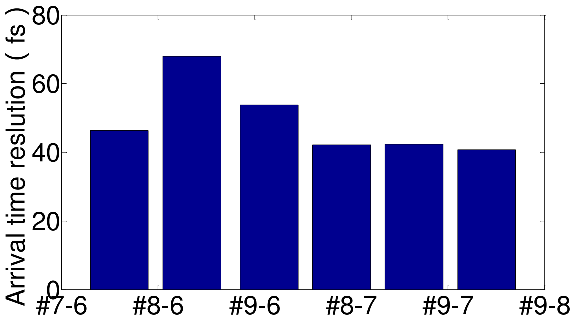

Figure 8: Beam arrival time uncertainty

IF Signal Analysis

By measuring the arrival time with two pickups, the BAT resolution was determined. we measured the IF signal in different beam charge and signal attenuation. Figure 9 shows the results.

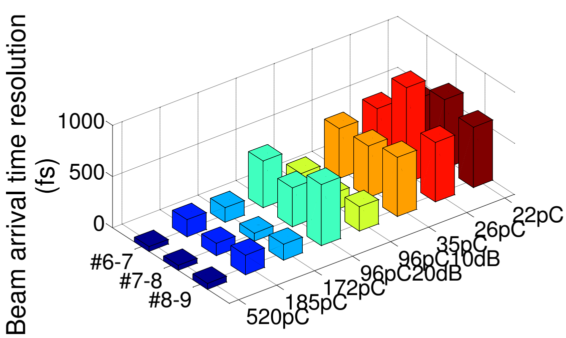

Figure 9: Beam arrival time resolution

Choosing one group of the BAMs and calculating the SNR in different charge and attenuation, hence the dependence of BAT resolution on SNR can be plotted, as shown in Fig. 10. In this figure, BAT resolution is inversely proportional to SNR and the variation tendency is similar to the simulation results. Considering there are many error sources during measurement, the value difference is understandable.

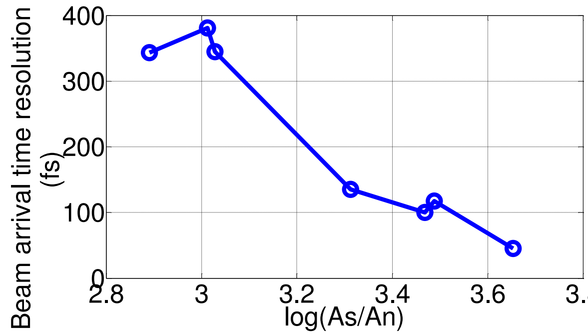

Figure 10: Beam arrival time resolution in different SNR

CONCLUSION

We measured the beam arrival time resolution with four CBPMs at DCLS. By measuring the phase difference between two adjacent cavities, an optimal arrival time resolution was found to be 32 fs. By comparing the results of RF signal and IF signal, the latter resolution and stability can be better than that of the former one when the SNR is large. Moreover, from the simulation results, BAT resolution is inversely proportional to SNR and sampling rate. Combining simulation and experimental results, the former is much better than the latter which is reasonable for different noise in the experimental environment. Furthermore, the above results can be used to predict the limitation of BAT resolution and give a lowest limit of SNR for a given resolution.

REFERENCES

[1] H.X Deng, M Zhang, D Gu, *et al.*, “Simulation studies on laser pulse stability for Dalian coherent light source”, *Chinese Physics C.*, vol. 38, no. 2, p. 91-96, 2014.

[2] T Zhang, H.X Deng, W.Q Zhang, *et al.*, “FEL polarization control studies on Dalian coherent light source”, *Chinese Physics C.*, vol. 37, no. 11, p. 108113, 2013.

[3] B.P. Wang, Y.B. Leng *et al.*, “Design and measurement of signal processing system for cavity beam position monitor”, *Nuclear Science and Techniques*, vol. 24, no. 2, p.1-6, 2013.

[4] Han J. H., Hong J. H., Kim C., Yang H., “Bunch Arrival Time Monitor Test at PAL-XFEL ITF”, in *Proc. IPAC’16*, Busan, Korea, May 2016, MOPMB058, pp.223.

[5] Brachmann, Bostedt C., Bozek J., *et al.*, “Femtosecond operation of the LCLS for user experiments”, in *Proc. IPAC’10*, Kyoto, Japan, May 2010, paper MOP623, pp. 338.

ISBN 978-3-95450-182-3