VARIATION OF BEAM ARRIVAL TIMING AT SACLA

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Abstract

SPring-8 Angstrom Compact Laser (SACLA) is a XFEL facility which provides intense pulsed X-ray laser to various scientific fields. It is a key issue to deliver stable timing signals to the accelerator components, the beam monitor units and apparatus of XFEL users with a precision of less than 100 fs RMS. Since the arrival timing of the X-ray at an experimental station depends on that of the electron beam, we measured the arrival timing of the electron beam by comparing a reference rf signal and a beam induced signal from an rf beam position monitor (RF BPM). A jitter of the arrival timing monitor was 41 fs in RMS calculated from a correlation plot of two adjacent BPMs data. To evaluate the stability of the timing monitor, we measured the difference of the arrival timings between two BPMs located at the entrance and the exit of the BL3 section. The difference of the arrival timings was about 180 fs pk-pk for 2 days measurement, which is the present accuracy of our beam arrival timing monitor.

INTRODUCTION

SACLA is a XFEL facility at SPring-8 [1]. For the accelerator of this facility, it is important to stabilize the phases of the accelerating cavities around the injector and bunch compression process of SACLA within 100 fs RMS to keep the stable laser oscillation. For this purpose a transmission system to deliver reference rf signals though optical fibers was installed [2]. One method to evaluate the stability of the transmission system is to measure the difference between two beam arrival timings along a straight beam-drift section. The high energy electron beam reaches almost the speed of light and hence, the difference of the beam arrival timings measured at two points along the straight beam-drift section is constant. If the optical path length is changed in the transmission system, the change also appears in the difference between the beam arrival timings. We have a beam position monitor which can measure the phase as beam arrival timing between the beam induced signal and the reference rf signal [3, 4]. Its temporal resolution was evaluated at the SCSS test accelerator and was measured to be 25 fs in RMS [5]. We measured again this temporal resolution at SACLA by using two adjacent BPMs. Then we measured the difference of the beam arrival timing between two BPMs located at the entrance and the exit of a BL3 undulator straight section. The measurement results of the arrival timing and the stability of the reference signal transmission system are reported in this paper.

BPM SYSTEM AND TRANSMISSION SYSTEM OF REFERENCE RF SIGNALS

To attain the submicron position measurement resolution, a cavity type BPM is used at SACLA [3, 4]. It consists of two cavities; one is a TM110 dipole mode cavity in order to measure the beam position, and the other is a TM010 monopole mode cavity to measure a beam charge amount and a reference beam phase for normalization. The resonant frequencies of the cavities are 4760 MHz. The BPM electronic circuit consists of an In-phase Quadrature (IQ) demodulator in order to detect the amplitude and the phase of the signal. The detected

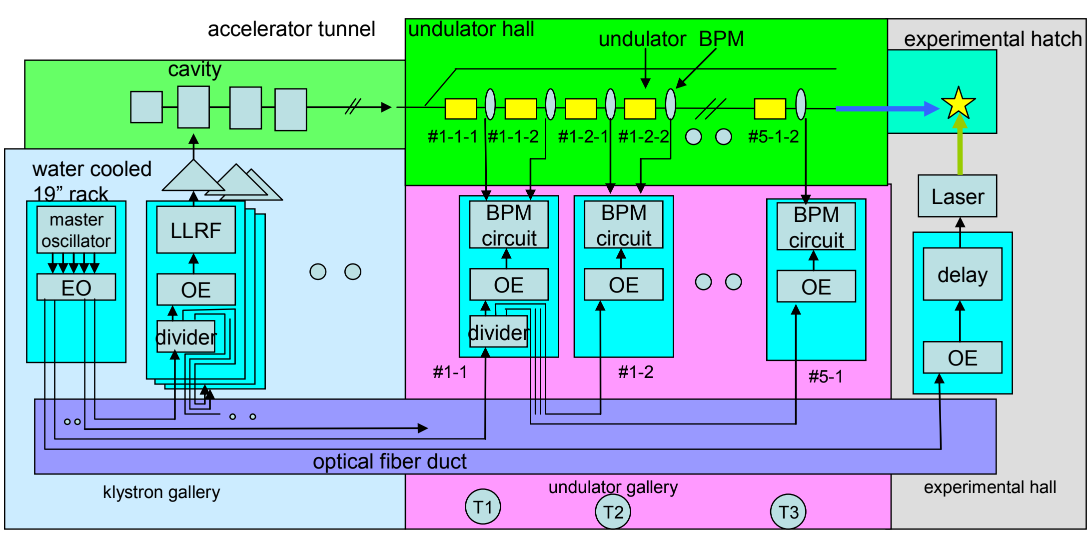

Figure 1: Schematic view of the BPM system and the transmission system of the reference rf signals.

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baseband signal is digitized by a 16-bit 238 MS/s ADC and stored in a database. Each data set has a tag number corresponding to the beam shot and by using this tag number we can analyze the correlation with other signals such as the intensity of the X-ray and so on.

Electronic circuits, such as the IQ demodulator, the ADC and an optical receiver for the reference rf signals (O/E) are installed in a temperature controlled 19" rack. The rack has a thermal insulation and air inside the rack is circulated through a heat exchanger to which temperature-controlled cooling water within 0.1 K is fed. Figure 1 shows a schematic view of a BPM system and the optical transmission system of the reference rf signals. A master oscillator generates the reference rf signals and they are converted into the optical signals by an optical transmitter (E/O). The optical signals are transmitted to receiving points through optical fiber cables. The optical cables are installed in a thermally insulated duct where temperature controlled water is circulated [2].

RESULTS

Resolution of the Arrival Timing Monitor

The temporal (phase) measurement resolution of the BPM system was checked by using two BPMs located at places upstream and downstream of a BL3 undulator #1-2-2. The distance between the two BPMs was 6 m. The measurement was done with conditions that the beam charge was 0.2 nC, the repetition rate of the beam was 10 Hz and measurement time was 10 seconds. Figure 2 shows the correlation plot of both the measured phases. The RMS value of the phase deviation from the fitted line is 0.10 degree at 4760 MHz, which corresponds to 58 fs. The temporal resolution is $1/\sqrt{2}$ of this value if the resolutions of these two BPMs are same. Therefore the resolution was 58 fs $/\sqrt{2}$ = 41 fs. This value is larger than that described in Ref. [4] by a factor of 1.7. It is because the signal level of SACLA was smaller than that of the SCSS test accelerator. Figure 3 shows an example of a pickup signal of the BPM and a detected signal from the

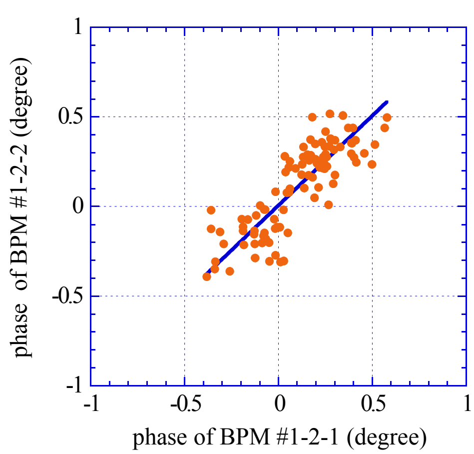

Figure 2: A correlation plot of the measured phases from two adjacent BPMs.

IQ demodulator. The peak voltage of the pickup signal was 0.2 V and that of the detected signal was 0.15 V. On the other hand, the pickup signal in Ref. [4] was about 0.7 V, which was nearly the full scale of the demodulator and the ADC of 1.0 V.

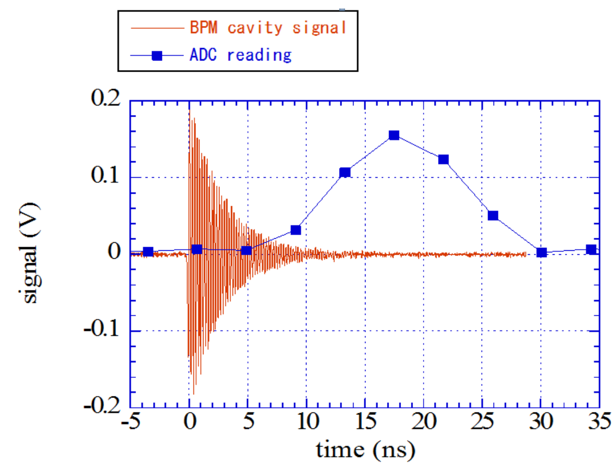

Figure 3: A waveform from a BPM reference cavity and an output signal from an IQ demodulator. The beam charge was 0.2 nC.

If the attenuation value is optimized to a specific beam charge amount, the temporal resolution is improved at SACLA. The attenuation value was set to avoid saturation of the electronic circuit at various beam charge. The temporal resolutions of eighteen BPMs at BL3 were varied from 40 fs to 100 fs according to the attenuation values.

We can improve the temporal resolution by making an average of several BPMs' data. Figure 4 shows the temporal drift of the measured beam phase for 10 second. In this figure the averaged value of the phases of the eighteen BPMs located along the BL3 undulator section for each beam shot was also shown. The RMS values of beam phases of BPM #1-2-1 and #1-2-2 for 100 shots are 0.11 degree (65 fs) and 0.09 degree (52 fs), which are

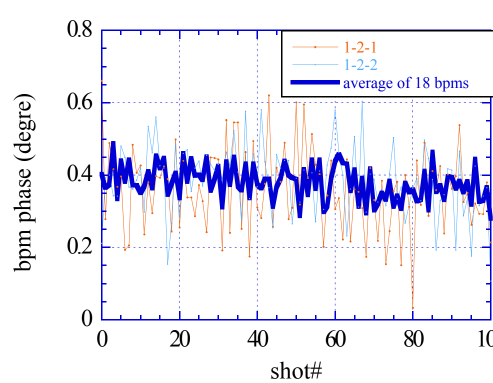

Figure 4: The trend of the beam phases of the two BPMs for 10 second measurement. The averaged phase of the eighteen BPMs located at the BL3 undulator is also shown.

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over 50 fs. On the other hand that of the average value of 18 BPM data is 0.05degree (27 fs), which shows a reduction of the RMS jitter.

Drift of the Beam Arrival Timing

We measured long term variation of the beam arrival time by using the BPM signal. Figure 5 shows an example of the measured result. The data was taken for two days at an entrance and an exit of the BL3 undulator section. The distance from the entrance and the exit of the undulator is about 110 m. In order to make clear the drift component, the averaged data of 16 points (time averaged) are also shown in the figure. The arrival timing of the averaged data was varied about 1 degree (600 fs). This drift was caused by a parameter drift of the accelerator whose detail is described in Ref. [5].

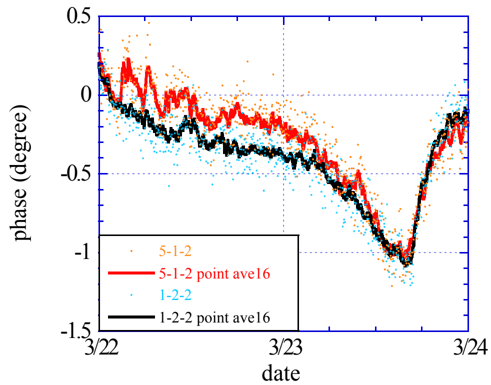

Figure 5: The BPM phases measured at an entrance (#1-2-2) and an exit (#5-1-2) of the BL3 undulator section for two days.

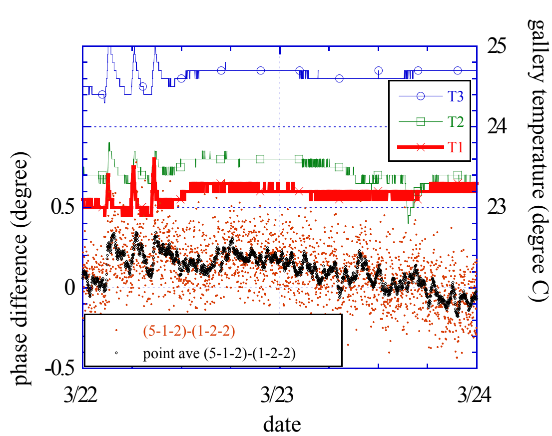

Figure 6: The trend of the phase difference of two BPMs at the BL3 undulator section (red and black dots). Some of the ambient temperatures in the undulator gallery where the optical cable and the 19” racks are located are also shown (solid lines).

Performance of the Reference Transmission System

As described in the introduction, the time difference of the beam arrival timings of two BPMs located at the straight section provides information of the stability of the reference rf signal transmission system. In Fig. 6, the difference of the beam arrival timing between the entrance and the exit of the undulator section was shown. The arrival timing data averaged by measured 16 single point data is also shown in black dots. The variation of the averaged arrival timing difference was about 0.3 degree (180 fs).

Then we tried to find out the source of the variation. The ambient temperatures of the undulator gallery where the optical fiber duct and the 19” racks are located are shown in Fig. 7. The temperature had a fluctuation of 0.8 K pk-pk with a period of about 2 hours from 0:00 to 12:00 March 22nd. The difference of the beam phase at this period also had a fluctuation of 0.2 degree (120 fs) correlated with the variation of the temperature. From the previous experiment, the temperature variation of the thermally insulated duct of the optical fibers was affected by the ambient temperature, but it was within 0.12 K even if the ambient temperature was changed 3.4 K [6]. Therefore, the length change of the optical fiber of 150 m is calculated as follows; 5 fs/K/m * 150 m * 0.12 K ~ 90 fs.

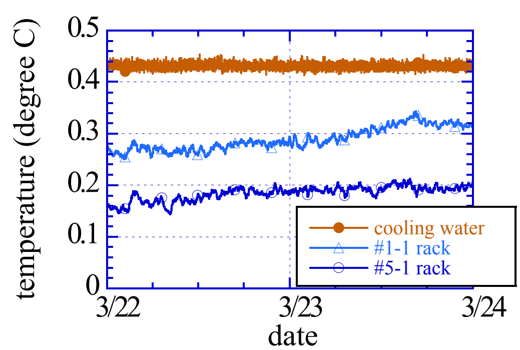

Figure 7: A temperature of the cooling water of the undulator section and 19” racks of #1-1 and #5-1 BPMs.

The temperature of the cooling water was kept constant within 0.05 K as shown in Fig. 7. The temperatures inside the 19” racks had a small drift of +0.06 K at the rack #1-1 and +0.04 K at the rack #5-1, which were located at the entrance and the exit of the BL3, respectively. The thermal phase (time) coefficients of the optical receiver for the reference rf signals, the IQ demodulator and the rf cable at the ambient temperature of 28 degree Celsius were -1200 fs/K, 18 fs/K and 60 fs/K/m, respectively. The contributions in time variations were -70 fs by the optical receiver, 1 fs by the IQ demodulator and 7 fs with 2m long cable as summarized in the table 1. The variation of the beam arrival time was mainly caused by the

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temperature change of the reference rf transmission components; the optical fiber and the optical receiver.

Table 1: Contribution to the Variation of the Beam Arrival Time

Elements	Temperature coefficient	Temperature variation	Time variation
Optical fiber	5 fs/K/m * 150 m	0.12 K	90 fs
Optical receiver (O/E)	-1200 fs/K	0.06 K	-70 fs
IQ demodulator	18 fs/K	0.06 K	1 fs
RF cable	60 fs/K/m * 2m	0.06 K	7 fs

SUMMARY

We measured the beam arrival timing by using a BPM signal. The temporal resolution of the arrival timing measurement with a BPM system was evaluated by using a correlation plot of data from two adjacent BPMs and found to be 41 fs by measurement for 10 seconds. The time difference between two BPMs located at positions along a straight section, with which are apart for a distance of 110 m each other, was measured in order to evaluate the stability of the reference rf transmission system. It was about 180 fs pk-pk taken by two days measurement. This value is acceptable level for our demand at the current stage, but it should be suppressed. One of the sources of this variation is length variation of optical cables caused by the thermal variation of a duct. This situation will be improved by introducing an optical fiber length control system and this system will be installed in this fiscal year [7]. Another contribution was found to be the large phase variation coefficient as the temperature of the O/E. A counter measure to this drift is to introduce more precise temperature control of the 19” rack, and this approach is applied to the injector section of the accelerator at SACLA [5].

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