Development of Laser-SR Synchronization System

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1. Introduction

Synchronization of a short pulse laser and SR (synchrotron radiation) pulses is essential for SR + laser pump-probe experiments, the mixing of X-rays and optical photons, and coherent harmonic generation using electron beams. Synchronization has been performed at LURE, UVSOR, BESSY, and third generation SR facilities. The required precision and monitoring techniques for synchronization are, however, dependent on the SR facilities, because they are determined by the time structure and photon energy of the SR. Since the pulse duration of the SPring-8 SR is typically 40 ps (FWHM), a synchronization technique with a precision of less than a few tens of ps is required at SPring-8 in order to achieve the perfect overlap of both pulses. A system to monitor the timing of both beams with the required temporal resolution should also be developed, because the optical cross correlation technique is still not available for the hard X-ray SR + laser combination. In this report, we describe the laser-SR synchronization system together with a timing monitor using an X-ray streak camera, and an experimental evaluation of the synchronization, followed by the measurement of undulator gap-dependent arrival time shift of the SR pulses.

2. Instrumentation

2.1 Laser-System Synchronized with an RF Master Oscillator

Figure 1 shows a sketch of a laser-SR synchronization system developed at BL29XU. The laser system was installed in a booth with a safety interlock for class IV lasers. The reference signal for the trigger was provided by a master oscillator of the RF system for storage ring acceleration (508.58 MHz). Since the trigger source was located 220 m from the laser system, an optical fiber cable with a small temperature dependence of propagation time (5 ps/km/K) was used to guide the RF signal to the laser booth by way of E/O converters. The signal was transformed into an 84.76 MHz signal with a 1/6 digital counter, and then introduced to the laser oscillator.

The laser system is basically composed of a mode-locked Ti:sapphire oscillator (SP (Spectra-Physics Lasers), Lok-to-Clock Tsunami) and a regenerative amplifier (SP, Spitfire). The mode-locked oscillator has a repetition rate determined by its cavity length. By controlling the cavity length with a phase lock electronics module (SP, model 3930), the output pulse train was locked to the provided 84.76 MHz signal. The Ti:sapphire oscillator was pumped by an SH (second harmonic) of a Nd:YVO_4 laser, and it produced pulses with a duration of 80 fs, an average power of 700 mW at a wavelength of 800 nm. This laser beam was guided to the regenerative amplifier, which was pumped by the SH of a diode laser pumped 1 kHz Q-switched Nd:YLF laser. The timing for Q-switching was also triggered by external reference, which was carried out using an 84.76 MHz reference signal with a 1/*n* counter (*n*=84854) together with a digital delay pulse generator (SRS, DG535). The number *n* was determined in consideration of the harmonic number, 2436, of SPring-8, so that the laser pulses met the SR pulses originated from a particular electron bunch. The regenerative amplifier was composed of a cavity with a gain medium of Ti:sapphire and a pulse stretcher/compressor

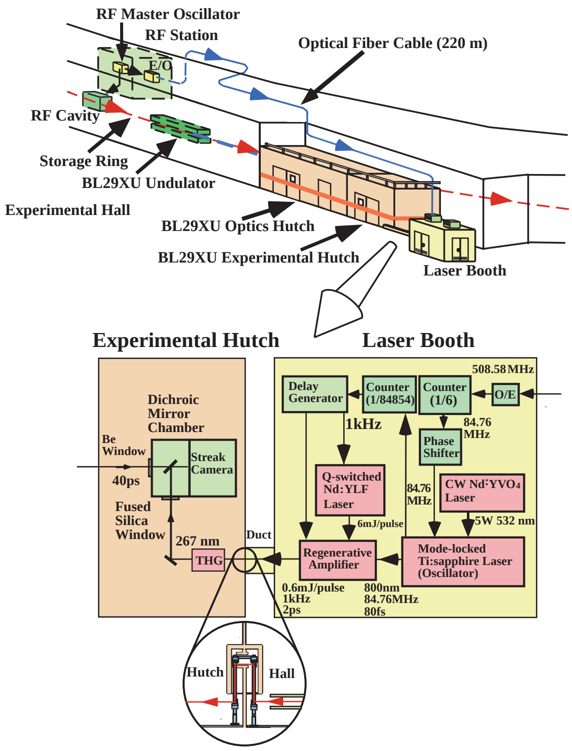

Fig. 1. Sketch of laser-SR synchronization system.

assembly. A set of slits in the stretcher/compressor worked as a band-pass filter, and consequently produced picosecond pulses. The output pulse produced a pulse energy of 600 μJ and a pulse duration of 2.0 ps (FWHM).

The output beam of the regenerative amplifier was guided out of the laser booth into the experimental hutch through a duct with Ag steering mirrors (see Fig. 1). Second and third harmonics were generated in the experimental hutch using BBO crystals. The third harmonic UV beam (267 nm) with a pulse energy of 1.6 μJ, was guided to a streak camera.

2.2 Timing Monitor

A picosecond streak camera (Hamamatsu, C5680-06) with a dichroic mirror chamber was installed inside the experimental hutch to monitor the timing of the SR and the laser pulses by applying both beams simultaneously on the same photocathode. The photocathode was composed of a 30 nm-thick gold film, allowing the detection of radiation at both energies of 16 keV (SR) and 4.7 eV (laser), which are higher than the work function of gold (4.3 eV). This method has the advantage of giving a precise measurement of the interval between both beams without being affected by the drift of the trigger timing of the streak camera.

The dichroic mirror chamber contained Be and fused silica windows on the front and side flanges respectively. A 0.5 mm-thick aluminum plate mounted at the end of the manipulator was centered in the vacuum chamber. This plate worked as a dichroic mirror and featured high reflectance for the UV laser beam and 42 % transmittance for the SR at 16 keV. As illustrated in Fig.1, the UV laser pulse is guided through the fused silica window to the center of the dichroic mirror and then reflected onto the photocathode of the streak camera.

The streak camera was operated with a synchroscan plug-in, which provided a fast time sweep with 160 ps and 800 ps ranges in full scale. The streak images on the screen were read out by a charge-coupled device (CCD) camera, and digitized information was transferred to a personal computer.

3. Results and Discussion

3.1. Evaluation of Synchronization

In order to estimate the jitter between the laser output pulses and the RF master oscillator, we used a digital sampling oscilloscope (Tektronix, 11801C) with a fast sampling head, the bandwidth of which is 50 GHz, and rise time 7.0 ps. Figure 2 shows the distribution of timing between the RF reference (508.58 MHz) and the output of the 1/6 counter (84.76 MHz) observed on the screen of the oscilloscope. The distribution of timing between the 508.58 MHz reference and the laser output obtained with a picosecond photodetector is also shown in Fig. 2. The jitter of the sampling oscilloscope itself was measured by applying the RF reference both to the sampling head and the trigger input, and was found to be 4.4 ps (FWHM). Through deconvolution, the jitter originated from the 1/6 counter was estimated to be 14 ps (FWHM). The jitter between the 508.58 MHz reference and the laser output was also obtained to be less than 2.4 ps (FWHM). The smaller jitter less than that of the 1/6 counter, implies that the repetition rate of the laser is not affected by the trigger jitter, since the phase lock feedback does not respond to the fast pulse-to-pulse jitter on the trigger.

3.2 Fine Adjustment of Timing as Monitored with the Streak Camera

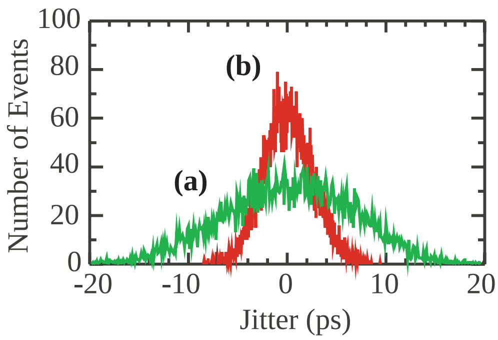

Fig. 2. (a): The timing jitter between the 508.58 MHz RF reference and the laser pulses, including the jitters of an oscilloscope and a photodetector. (b): The jitter originating from the 1/6 counter.

The time interval between the SR and laser pulses can be controlled with a resolution of ≈1 ps as monitored with the streak camera [1]. The tuning of the laser pulse timing to overlap perfectly with the SR pulse is shown in Fig. 3. The timing has been adjusted by the phase shifter. In Fig. 3, Δt represents the observed time interval between the SR and the laser pulse. Starting from Δt = 105 ps (Fig. 3(i)), we made Δt gradually smaller and obtained Δt = -4 ps for (v). It may be noted that the positions of the laser pulses on the screen are slightly changed for (i)-(v), because of the abrupt drift of the streak trigger. The trigger timing to the sweep of the streak camera was changed between (v) and (vi) to find both pulses on the center of the screen. Then, the perfect overlap is seen in (vi).

The long-term stability of synchronization was also measured because it is required for the pump-probe experiments, in which integration must be carried out in order to obtain small signals. The timing of both

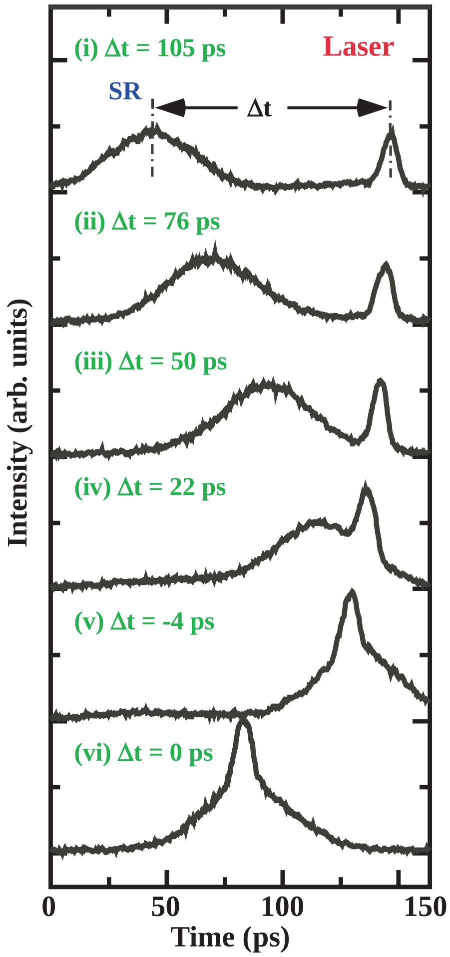

Fig. 3. Tuning of the laser pulse timing to overlap with the SR pulses.

pulses was stable for hours within a distribution of ±2 ps, which is much smaller than the SR pulse width.

Thus, the laser-SR synchronization system can achieve the temporal overlap of both pulses as well as a fixed time interval with a long-term stability of a few ps.

3.3 Demonstration of the Arrival Time Shift of SR Pulses by Closing the Undulator Gaps

Using the synchronization system with a precision of ±2 ps, we measured the time drift of the centroid in the SR pulse due to the electron energy loss produced by the undulator radiation [1]. Figure 4(a) shows the experimental result obtained when only the BL29XU undulator gap was closed in the storage ring. The interval between the SR and laser pulses is found to be 42.2 ps. Then 14 undulators were closed, and Fig. 4(b) was obtained, in which the interval is found to be zero. The timing of the SR is consequently found to gain 42.2 ps. The result is consistent with the theoretical expectation through the following relation:

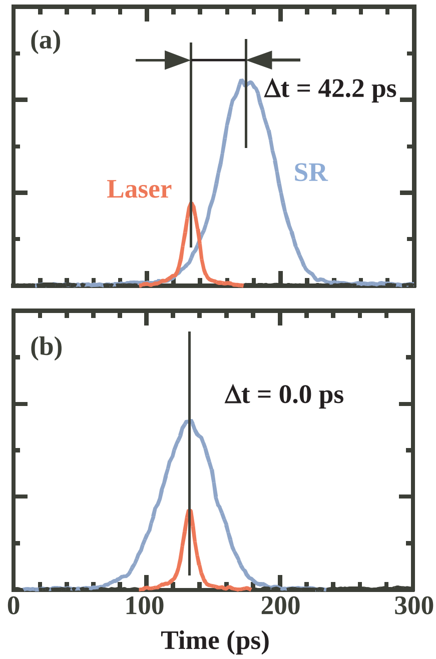

Fig. 4. Temporal drift of the SR pulses due to the electron energy loss produced by the undulator radiation. The graphs are obtained in a condition where the undulator gaps were open (a), and the 14 undulators were closed (b).

$$\sin\phi = P_l\,(V_0 \times I),\ (90° \le \phi \le 180°). \qquad (1)$$

Here, ϕ is the phase of the RF electric field, where the electrons in the storage ring keep their energy balance. P_l , V_0, and I are the power loss of electrons, total peak voltage of the RF cavities, and ring current, respectively.

It is to be noted that the high precision of the timing control system can also observe any effect of the undulator gaps changed by the beamline users. In order to keep the timing stability of ±2 ps, we should install a feedback system to compensate the arrival time drift of the SR pulse.

References

[1] Y. Tanaka *et al.*, Rev. Sci. Instrum. **71** (2000) 1268.