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FEMTOSECOND FIBER LINK STABILIZATION TO TIMING SYNCHRONIZATION SYSTEM FOR SHINE PROJECT*

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Abstract

The under-construction Shanghai high repetition rate XFEL and Extreme light facility (SHINE) project has a high precision requirement for the timing synchronization system on femtosecond timescale over more than 3-km long optical fiber links, therefor, an ultra –low noise reference signals from the optical master oscillator (OMO) transmission is play an important role. For this purpose, a fiber link stabilization units based on balanced optical cross-correlators to stable the long-distance fiber link is under developing.

In this paper, the latest progress of the fiber link stabilization experiment and measured results for the performance will be reported.

INTRODUCTION

FELs facilities can generate bright, coherent X-ray pulses with temporal duration below 100 fs and up to 10^{13} photon per pulse [1]. Such high brightness and ultra-short pulses light source facilities put forward higher requirements for the accuracy of timing synchronization system. The traditional RF method cannot meet the XFEL's femtosecond precision synchronization requirements on femtosecond timescale. According to the timing synchronization schemes of several major FELs facilities under operation all over the world, such as FLASH, the European XFEL, and FERMI FEL [2-5], we have conducted research on femtosecond synchronization system as is shown in Fig. 1. For such a timing system, it is essential to stabilize the long-distance fiber link to provide the drift and jitter-free reference pulsed optical signals to multiple terminals, including photo-injector laser, seed laser, RF system, user experiment stations, bunch arrival time monitors and so on.

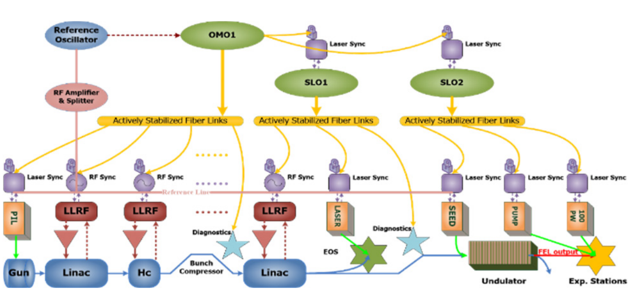

Figure 1: Schematic of typical femtosecond synchronization system.

Fiber link stabilization system based on a mode-locked fiber laser (OMO), which locked on a RF master oscillator (RMO), using the a phase detector called balanced optical cross-correlators (BOC) due to its attosecond timing resolution, long-term stability, amplitude invariance and robustness against environmental fluctuations.

PRINCIPLE OF FIBER LINK STABILAZAION

BOCs is a highly sensitive method to measure timing fluctuations between optical pulses and it can be also employed to detect time of flight fluctuations of pulses circulating in a fiber link [5]. Figure 2 shows the timing detection principle of BOC, the relative timing of both input optical pulse is to be measured by the double-pass configuration. BOC is based on the second-harmonic generation (SHG) between two orthogonal polarizations pulses in a non-linear crystal PPKTP [6, 7]. The forward two pulses with a time delay Δt transmitted through the dichroic mirror (DBS1), overlap in the crystal and generate the SH1. The residue fundamental pulse is reflected by the DBS2, and backward into the crystal second time, generate another second harmonic signal SH2. A balanced photodetector receives the both SHG signals separately, and the output indicates the time delay of both input pulses.

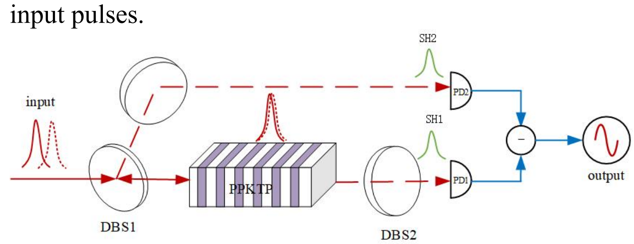

Figure 2: Principle of BOC.

Figure 3 illustrates the operation principle of fiber link stabilization using a BOC. Since the mode-locked laser can provide ultra-low noise optical and microwave signals in the form of optical pulse trains, it has great advantage as the optical master oscillator (OMO) for the high precision timing synchronization system.

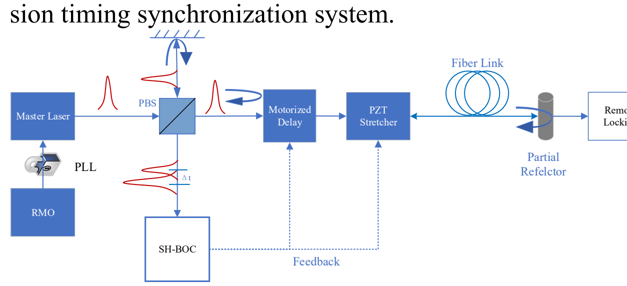

Figure 3: Operation principle of fiber link stabilization.

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OMO is locked in a RF master oscillator with low jitter using phase-locked-loop method. The pulse from OMO is divide into two paths: one is for reference pulses and the other for fiber link pulses. Fiber link pulses go through the long distance to the remote site. There is a partially reflector at the end of the link, and the pulses back to the fiber link will be combined with the reference pulses going through into the BOC. The output time delay between the two pulses will be used as a feedback to control the motorized delay and PZT stretcher to stabilize the long-distance fiber link.

EXPERIMENT SETUP

The experiment schematic of fiber link stabilization unit in laboratory is shown in Fig. 4. The OMO is manufactured by Menhir, which provide the optical pulse with centre wavelength at 1550 nm, FWHW pulse duration of 150 fs, and repetition rate of 216.77 MHz. The pulse train from the master laser is divided by a 1×4 fiber splitter into four parts with different power. One part is for in-loop BOC and anther one is for out-of-loop BOC.

For in-loop BOC, optical pulse train is divided into two paths by PBS: the reference path and the fiber link path. To avoid the instability caused by the environment, the reference optical path should be as short as possible [8, 9]. The laser pulses in the free space go through a fiber collimator (Throlabs TC12APC-1550) into the fiber link, which including a motorized optical delay line (ODL), fiber stretcher, aerbium-doped fiber amplifier (EDFA), a 40-m fiber link, and a 90/10 transmission/reflection fiber-coupled Faraday rotator (FC-FR). The 40-m fiber link is comprised of 10-m of dispersion-compensating fiber (DCF) and 30-m of standard single-mode fiber (SMF). The FC-FR is placed at the end of the fiber link in order to simultaneously turn the polarization of the pulse by 90° and reflect the pulse train into the in-loop BOC1 detector for timing stabilization. In order to guarantee that the polarization state of the backward pulse from the SMF link exactly turn 90°, a half-wave plate and a quarter-wave plate aligned in front of the collimator is necessary.

To evaluate the performance of the link stabilization unit, a out-of-loop BOC2 is necessary. The output laser pulse from the link and fresh pulse from OMO are combined into out-of-loop BOC2. Once the in-loop section is locked with the feedback system, the output signals is used for the measurements of short-term timing jitter and long-term drift.

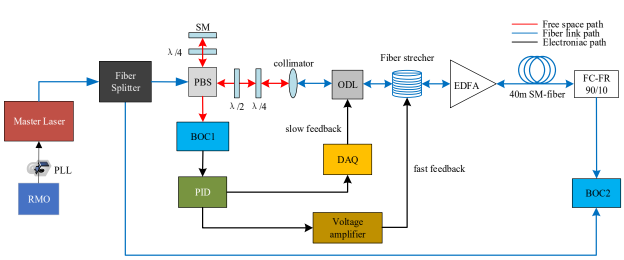
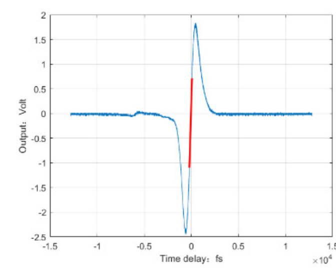


Figure 4: Schematic diagram of experimental setup.

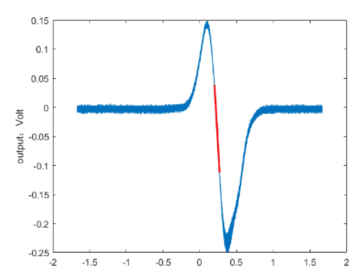
The BOC mainly consists of a dichroic mirror, a single periodically-poled KTiOPO4 (PPKTP) crystal (1 mm×2 mm×4 mm), and a balanced photodetector (Thorlabs PDB210A). The combined reference and fiber link pulses with orthogonal polarization states are transmitted through a dichroic mirror, which transmits the input pulse (1550 nm) and reflects the second harmonic pulse (775 nm). The back surface of the crystal is dichroic coated, which transmits the second harmonic pulse and reflects the input pulse. The output from the balanced photodetector is processed by a PID controller and divided into two paths: fast feedback and slow feedback. The fast feedback path is amplified by a voltage amplifier to control fiber stretcher, and the slow feedback path sampled by a data acquisition card and to control the motorized optical delay line with a turning range of 560 ps.

EXPERIMENTAL RESULTS

First, we measured the sensitivity of both in-loop and out-of-loop BOCs. The time delay curves of both BOCs are showed in Fig. 5(a) and Fig. 5 (b). The highest sensitivity of in-loop BOC is up to 6.4 mV/fs with the input power about +14.6dbm, and the out-of-loop sensitivity is about 2 mV/fs, with +11dbm reference power and +10dbm link output power.



(a)



(b)

Figure 5: Error out from in-loop and out-of-loop BOCs.

After stabilized the fiber link using the feedback system, the voltage noise spectral density has been measured by the baseband analyzer E5052B, and the analysed timing jitter result is RMS=3.17 fs from 1 Hz to 1 MHz, as is shown in Fig. 6.

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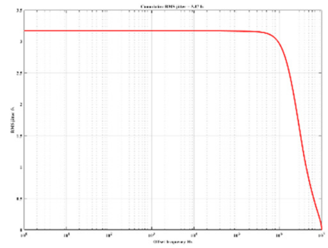

Figure 6: Analysed results of timing jitter.

CONCLUSION

We have setup a fiber link stabilization unit in laboratory to femtosecond timing synchronization system for SHINE project, and the performance have been measured. But considering our present system performed with the single mode fibers (SMF) maybe not reach the long-term stabilization requirements because of the polarization-mode-dispersion, we will update the SMF to polarization maintaining fiber (PMF) to improve the whole system performance to stabilize the kilometers-long fiber for SHINE project in the future.

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