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DEVELOPMENT OF THE FEMTOSECOND TIMING DISTRIBUTION SYSTEM FOR THE SHANGHAI SOFT X-RAY FREE ELECTRON LASER*

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Abstract

High accuracy timing and synchronization system on femtosecond timescale plays an important role for free-electron laser projects such as Shanghai Soft X-ray free-electron laser facility (SXFEL), and future Shanghai high repetition rate XFEL and Extreme light facility (SHINE). To meet the high precision synchronization requirements for both facilities, an optical based timing distribution system is necessary. Such system distributes the laser pulse train from a locked optical master oscillator through the fiber links, which stabilized by a balance optical cross-correlator based on a periodical-poled $KTiOPO_4$ crystal. In this paper, the recent developments and experimental results of SXFEL timing distribution system will be reported.

INTRODUCTION

High brightness and ultra-short pulses light source facility such as the SXFEL and SHINE projects put forward higher requirements for the accuracy of timing synchronization system. The traditional RF method cannot meet the XFEL's femtosecond precision synchronization requirements. 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 [1-4], we have conducted research on timing-stabilized fiber link distribution system based on a mode-locked laser (master) to provide the low noise reference signals to multiple terminals, including photo-injector laser, seed laser, RF system, user experiment stations and so on. Stabilized the long-distance fibers depend on a balanced optical cross-correlators (BOC) locking methods, using a periodically-poled KTiOPO4 (PPKTP) crystal, which can easily achieve tight locking with high locking bandwidth [4]. This paper will report recent experimental research status of the fiber link stabilization module with a 40-m fiber link for timing distribution system on SXFEL.

EXPERIMENTAL SETUP

The experiment schematic of fiber link stabilization system is shown in Fig. 1. 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. The OMO is manufactured by Onefive (Origami-15), which operates with a 238 MHz repetition rate, 190 fs pulse width, 1560 nm center wavelength and +17 dBm average output power. The pulse train from the master laser is divided by PBS into two paths: 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 [5, 6]. 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), a fiber stretcher, a erbium-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 BOC 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.

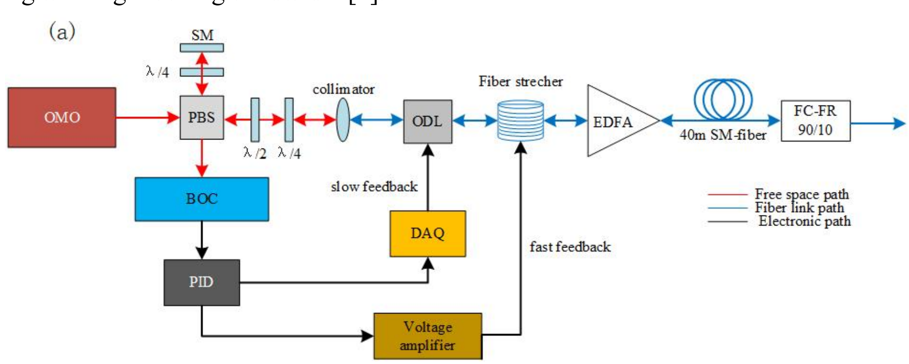

Figure 1: Schematic of the fiber link stabilization system.

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The in-loop 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), as is shown in Fig. 2. It is based on the second-harmonic generation (SHG) between two orthogonal polarizations in the PPKTP crystal [7, 8]. The combined reference and fiber link pulses with orthogonal polarization states are transmitted through a dichroic mirror (DBS), 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 balanced photodetector receives the both SHG pulse separately, and the output error signal indicates the delay change from the fiber link. Then the electronic signal 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.

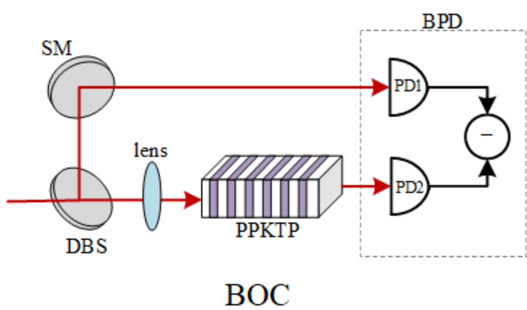

Figure 2: Main elements of BOC.

EXPERIMENTAL RESULTS

The first version of the fiber link stabilization module in laboratory is shown in Fig. 3.

Figure 3: First version for fiber link stabilization module in lab on SXFEL.

The fiber links should operate with a maximum power of +13 dBm to avoid the fiber nonlinearities [9], so the power distribution as followed: +13 dBm for reference path and +6 dBm for the fiber link path. The total loss in the fiber link is about 7 dBm. The output power at the forward direction of the EDFA is about 13 dBm, and there is 3 dBm back to the fiber link. The conversion efficiency of PPKTP crystal up to 0.8% for the best results. Due to the limitations of the experiment condition, we just measure the sensitivity and noise floor of the BOC. The sensitivity of BOC curve is showed in Fig. 4(a), is about 5.3 mV/fs. The noise floor measured by a SSA showed in Fig. 4(b), and the analyzed result is below 1 fs [10-10 MHz], as is shown in Fig. 4(c).

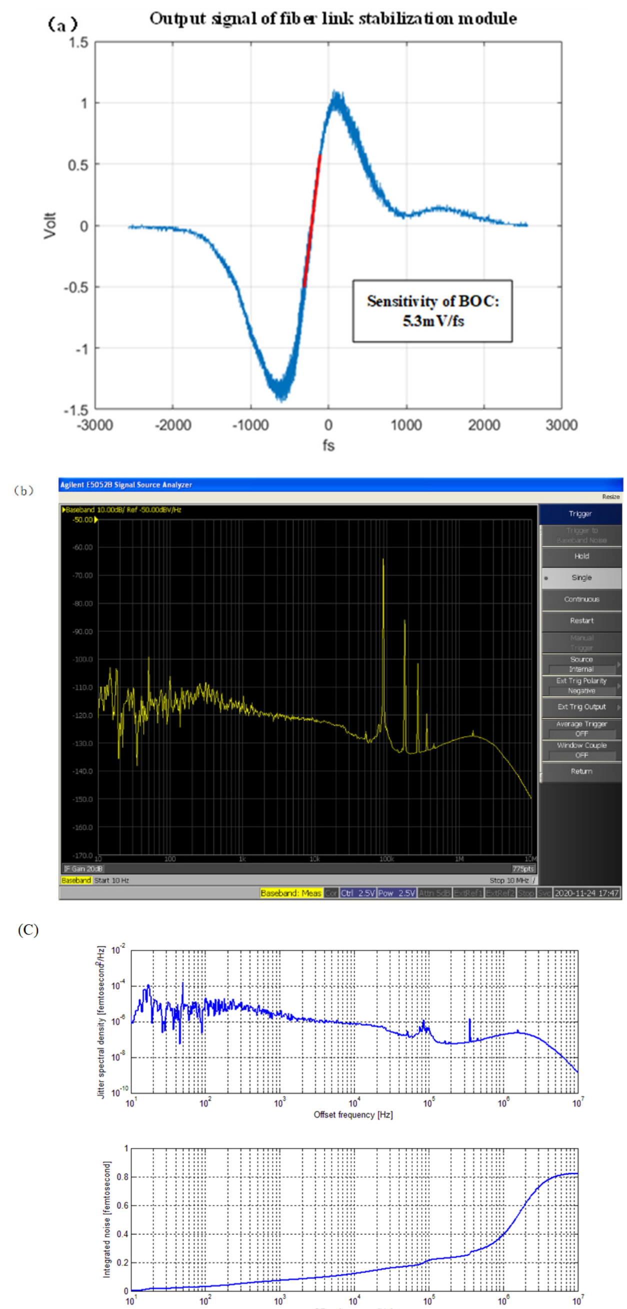

Figure 4: Experimental results of BOC: (a) output curve from the BOC and the slope shows the sensitivity about 5.3 mV/fs; (b) Noise floor result from SSA; (c) Analysis result of noise floor.

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CONCLUSION

The fiber link stabilization module of the timing distribution system has been established for SXFEL. The following work will focus on integrating with the electronic part and optimize the performance of the timing distribution system depending on the future more experimental results, such as long-term drift, phase noise, etc. And then we will update the single-mode fiber to polarization maintaining fiber (PMF) for more than 1-km distance fiber link stabilization.

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