CURRENT STATUS OF DEVELOPMENT OF OPTICAL SYNCHRONIZATION SYSTEM FOR PAL XFEL*

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Abstract

Optical synchronization system has been developed for higher quality PAL XFEL with low timing jitter since 2011. In last two years, laboratory test was successfully performed, and test in our accelerator environment is on-going. In PAL laboratory, we tested the synchronization of RF master oscillator (RMO) and optical master oscillator (OMO), the stabilization of 610 m optical fiber link, and the remote optical-to-RF conversion. We report recent our development results and summarize on-going optical timing project.

INTRODUCTION

Optical timing synchronization, which incorporates low loss optical fibers and phase-locked loops (PLLs) using optical reflection from the end, has been an established technique for low phase noise and long distance timing transmission [1-2]. This technique is widely used in femtosecond linear accelerators (LINACs) such as FLASH, FERMI, and LCLS. ≈1.1 km long PAL XFEL requires less than 50 fs timing jitter in the synchronization of lasers and RF systems for normal operations, and even less timing jitter is expected to improve the machine performance. In literatures, sub-femtosecond jitter in a km distance has been reported so far [3].

In XFEL, optical timing system has advantages to provide timing signals with ≈10 fs accuracy in a long distance without beam-based feedback. In this reason, we have been considered to use an optical timing system for PAL XFEL, and the development has been started since 2011.

In this report, we investigated the synchronization performance of a RF master oscillator (RMO) and an optical master oscillator (OMO), and a voltage controller oscillator (VCO) including a 610 m stabilized optical fiber link, which were demonstrated in our laboratory. Tests in our accelerator environment will be discussed at the end.

SYNCHRONIZATION TEST IN PAL LABORATORY

In 2012, we set up an optical timing test laboratory in a clean room. The typical configuration for the experiment is shown in Fig. 1. The temperature of the lab is maintained within 24±0.5 °C. Most instruments keep inside an acrylic box to reduce the effect of circulating air and acoustic noise. Free space parts are further insulated with Styrofoam as shown in Fig.1.

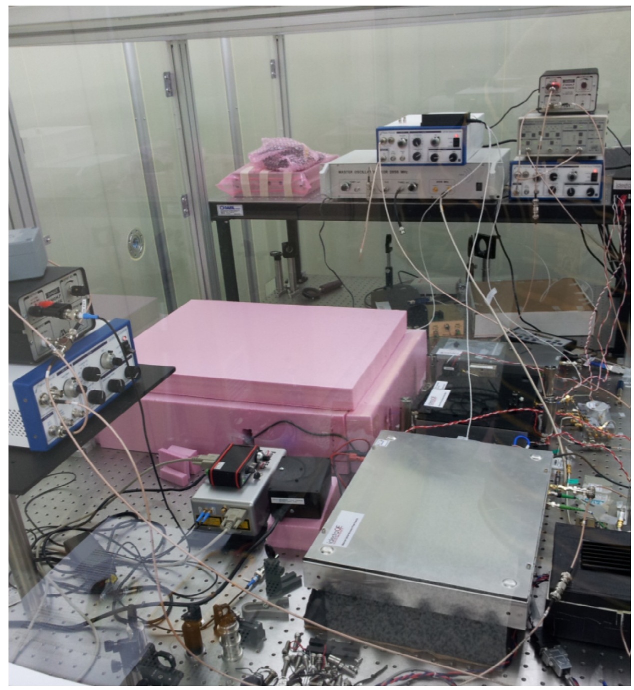

Figure 1: Picture from the laboratory test.

The experimental scheme is shown in Fig.2. RMO is synchronized to OMO using a balanced optical-microwave phase detector [4]. OMO is passive mode locked Er:fiber femtosecond laser which generates less than 100 fs pulses. RF frequency of RMO we used is S-band, 2.856 GHz and the repetition rate of OMO is 79.3 MHz, which is 36th sub-harmonics of RF. 10 nm band pass filter (BPF) is used to limit the bandwidth of optical spectrum before 610 m transmission. The limiting bandwidth helps to reduce the anomalous S-curve shape, which is originated from high order nonlinearity. Optical fiber is dispersion compensated by splicing a single mode fiber, SMF-28 and dispersion compensation fiber (DCF). To stabilize the group delay of the 610 m optical fiber, balanced optical crosscorrelator (BOC) detect the delay changes by the fluctuation of environmental variables and compensates the changes using a piezoelectric fiber stretcher and a motorized delay stage. After 610 m transmission, another phase detector, BOM-PD is used to detect timing error between optical pulse trains and VCO, which is also 2.856 GHz. The error signal feedback into VCO to lack between them.

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ISBN 978-3-95450-127-4

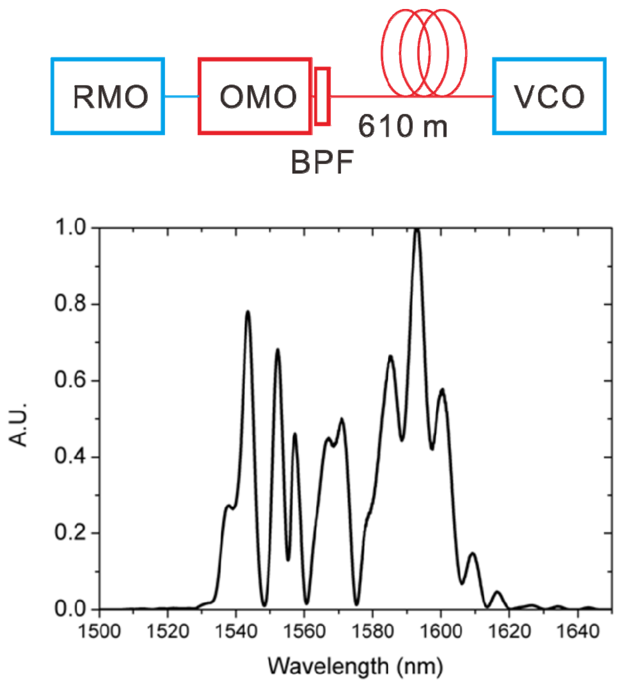

Figure 2: Experimental scheme and the spectrum of optical master oscillator.

The preliminary experimental results are summarized in Fig 3~5. Fig. 3 shows RMO phase noise and the residual phase noise after the synchronization of RMO and OMO using BOM-PD. OMO repetition rate was tuned by piezo electric transducer (PZT) to lock the frequency. The integrated timing jitter between them is measured 8.4 fs in the range of 1 Hz to 3 KHz. Fig. 4 shows the results of the synchronization of free running OMO and VCO using BOM-PD, and out-of-loop test. The control voltage of VCO was tuned to lock the frequency. The residual timing jitter become less and shows 4.4 fs at the same frequency range. Figure 5 shows in-loop timing jitter measurement of 610 m optical fiber link. The integrated jitter is as small as 0.5 fs in the range of 1 Hz to 100 KHz.

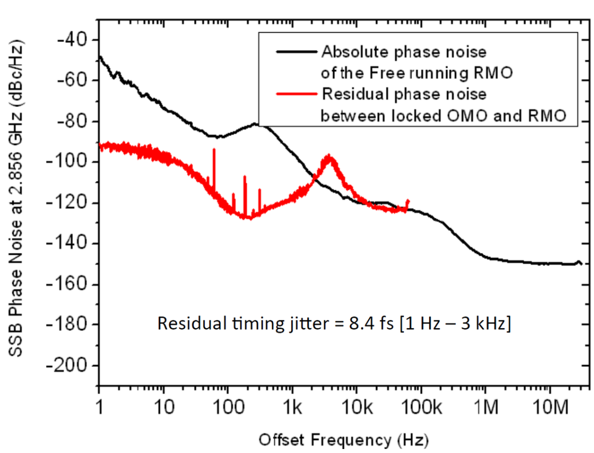

Figure 3: Phase noise measurement in the synchronization of RMO and OMO.

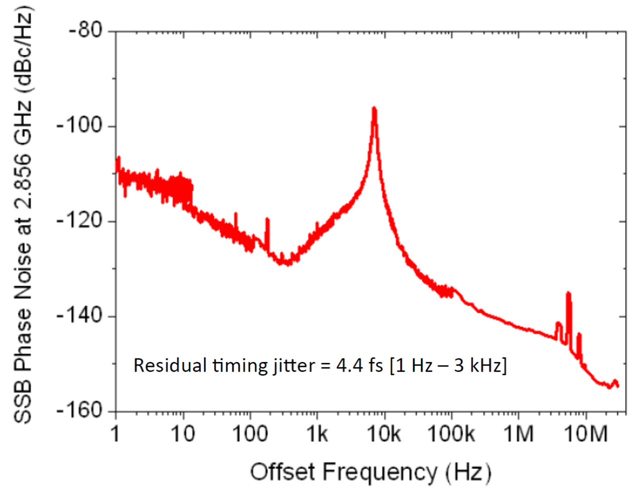

Figure 4: Residual phase noise measurement in the synchronization of RMO and VCO.

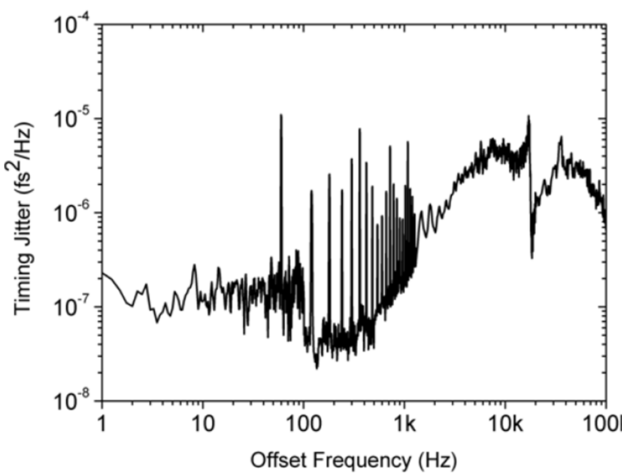

Figure 5: Timing jitter measurement of 610 m optical link.

Recently we measured the performance of OMO, optical link, and RMO using out–of-loop test and reported in FEL2013 conference. The results shows 2.7 fs jitter for 7 hours [5].

SYNCHRONIZATION TEST IN PAL ACCELERATOR ENVIRONMENT

We are planning to test optical synchronization system in more realistic condition, our accelerator environment after successful demonstration in the temperature controlled cleanroom.

Figure 6 shows the schematic layout of OMO room and injector test facility (ITF) in PAL. ITF was built in 2012 for XFEL injector test including two accelerator columns to generate electron energy up to 135 MeV. The red line in Fig. 6 is the route of optical transmission line. Two optical fibers installed between OMO room and injector laser room. Another two optical fibers are installed between OMO room and ITF gallery. Two fibers will be used to test the in-loop and the out-of-loop. The

ISBN 978-3-95450-127-4

experiment will test the immunity of our environmental variables in more realistic situations. The results will be able to be used to engineer real system in PAL XFEL.

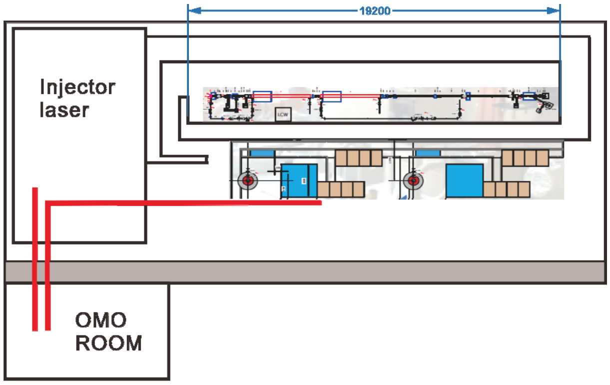

Figure 6: Test schematics in PAL accelerator environment.

SUMMARY

We have tested optical timing system for PAL XFEL since 2011. The preliminary results show that the performance of optical timing system is promising and precise engineering is required 24/7 operation and maintenance. We plan to test optical timing pulse transmission and RF regeneration in our accelerator environment, which has less temperature stability, more acoustic noise, and electrical noise. This would estimate the robustness of our optical timing system in PAL XFEL.

ACKNOWLEDGMENT

This work was supported by the PAL-XFEL Project, South Korea.

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ISBN 978-3-95450-127-4