SYNCHRONIZATION AND CONTROL SYSTEM FOR TSINGHUA THOMSON SCATTERING X-RAY SOURCE *

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Abstract

The Tsinghua Thomson scattering X-ray source (TTX) has a strict laser-electron synchronization requirement and a comprehensive system structure including dual high-power laser system, RF system and beam diagnostic instruments, etc. Recently, a synchronization and control system is developed to meet these requirements, which includes a laser-RF synchronizer with 100fs time jitter, a FPGA based event generator for laser and RF systems with 250ps time resolution, and an EPICS based control system for system integration and remote monitor and control. The electron bunch arrival time jitter is carefully measured and analyzed with the help of a RF deflecting cavity. This paper reports the development status, technical implementation, and measurement results of the synchronization and control system.

INTRODUCTION

TTX Synchronization and Control System Layout and Requirements

The TTX system [1] is designed for generation femtosecond hard X-ray beam by Thomson scattering of a low-emittance, ultra-short electron bunch and a terawatt laser beam.

The picosecond electron bunches are generated by a 1.5 cell photocathode RF gun and accelerated by an S-band linac. The laser system is designed to use a common home-made femtosecond Ti:sapphire oscillator at 79.33MHz repetition rate (1/36 of RF frequency) for both UV laser that triggers the RF gun and the terawatt IR laser, so that the time jitter between electron bunch and IR laser beam is minimized. The seed laser pulse is amplified by a regenerative amplifier (Coherent Evolution), and split for third harmonic generation and another stage of multi-pass amplification (Spectra-physics Quanta-ray Pro350) for terawatt IR pulse. A low phase noise microwave source at 2856MHz is used as the reference for both laser repetition rate and RF klystron.

In order to provide accurate event trigger signal for both CPA (Chirped Pulse Amplification) process and high power RF system, a customized timing system is developed.

The goal of synchronization system is to reduce system time jitter to promise a firm phase lock of laser-RF and electron-RF so that the arriving time of laser relative to electron bunch is controlled for a stable X-ray output and for better resolution of UED (Ultrafast Electron Diffraction) [2].

As shown in Fig 1, the local time jitter should be considered and measured for overall performance:

- Time jitter between laser oscillator and RF reference should be controlled below 200fs.
- Cavity RF amplitude and phase jitter should be controlled with in 0.5% and 0.5 degree to guarantee time of flight of electron bunch.
- Time jitter between amplified laser pulse and electron bunch, should be controlled below 500fs.

In order to meet those requirements, synchronization system must implement laser-RF phase lock loops, a digital low level RF control, and a small scale timing distribution system. Time jitter measurement and analysis apparatus with femtosecond sensitivity are also required to diagnostic each local synchronization performance.

TIMING SYSTEM DESIGN AND DEVELOPMENT

A home-made timing controller is developed on a single piece of Xilinx Spartan 3E FPGA, which consists of an embedded Picoblaze soft core, an internal/external reference multiplexer with automatic interlock, two digital clock synthesizer modules and 8 independent programmable counters for delay generation between channels.

The FPGA clock is derived from the frequency of a photodiode output from the laser oscillator, so that the edge of output gate signal is exactly locked to the laser pulse itself. In order to protect regenerative laser amplifier and keep outputting trigger signals in case of mode-lock failure of the oscillator, an external crystal oscillator at the same frequency is supplied, which would be switched by the multiplexer as soon as the mode lock frequency is gone.

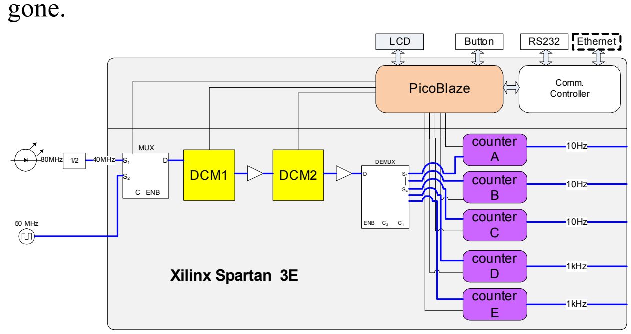

Figure 2: Single FPGA based timing system.

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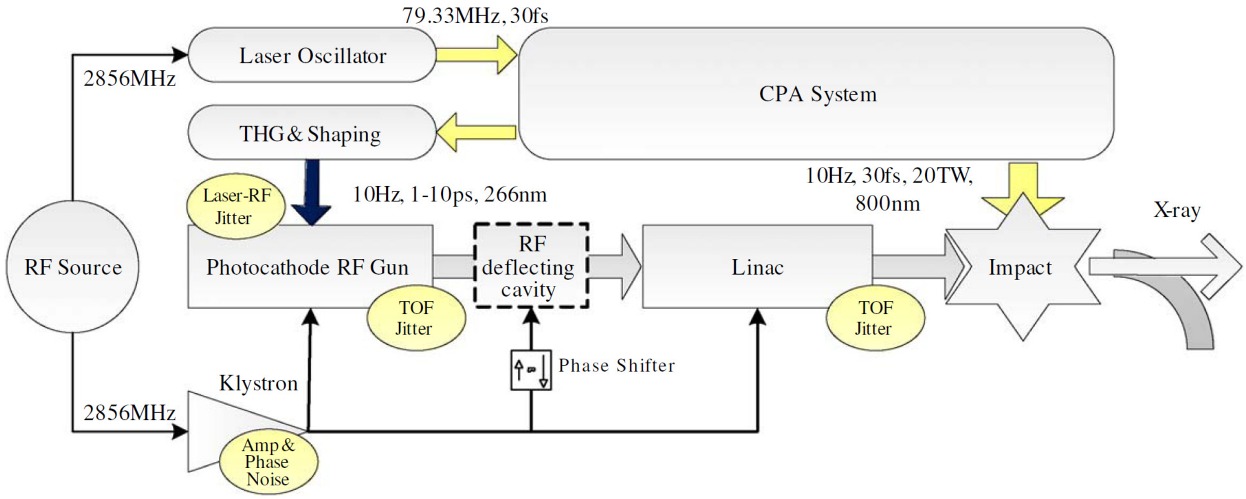

Figure 1: TTX System layout and synchronization interest points.

The soft core is capable of handling LED user interface, buttons and rotary switch control and remote communications. Parameters of delay time and rate of output channels are transferred to digital clock modules for calculation of frequency division number and delay counts.

The outputs of the timing controller trigger the Q-switch of regenerative laser amplifier, two pocker cell drivers, the lamp and Q-switch of multi-pass laser amplifier, klystron and RF system. Each channel has the tuning range of 250ps—1s delay at 10Hz/1KHz frequency.

LASER-RF SYNCHRONIZATION

The repetition rate of laser oscillator is locked to the RF reference at its 36^{th} harmonic of 2856MHz by a PI feedback controller with 10kHz bandwidth, compensating the cavity length by a small end mirror mounted at a Piezo actuator with high resonating frequency.

To measure the time jitter of laser-RF phase, an out-of-loop single side band phase noise measurement system is applied on carrier frequency of 2856MHz. Comparing with the time-domain measurement, the rms time jitter is measured as below 100fs [10Hz, 100kHz] [3].

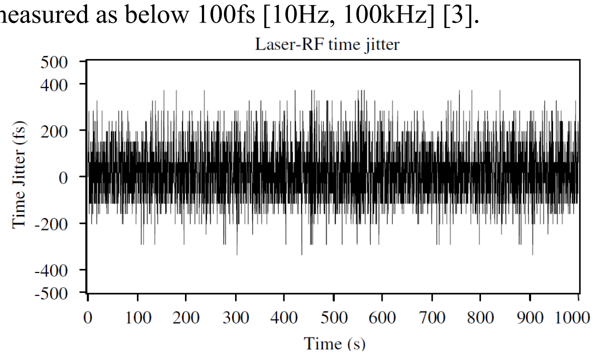

Fig. 3: The measured laser-RF rms time jitter is 92fs.

ELECTRON BEAM ARRIVE TIME JITTER MEASUREMENT

The RF amplitude and phase perturbation brought by RF amplification process in klystron is one of the major facts that affects the time of flight of electron bunch. Currently we do not have low level RF control system to stabilize it. But the measurement of electron bunch arrival time relative to RF phase is highly interested. In order to measure this parameter in femtosecond resolution, a RF deflecting cavity is installed just after the photocathode RF gun, and a phosphor screen is placed at the end of the beam line so that the bunch length and position could be measured after calibration.

Fig. 4 shows the electron bunch length as well as the longitudinal centre position during 10 minutes. The result tells that the rms time jitter of the arrival time is 540fs [3].

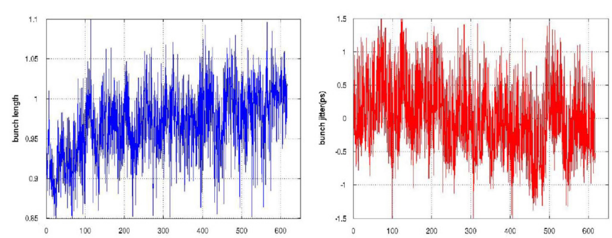

Fig. 4: Electron bunch arrival time relative to RF phase measured by RF deflecting cavity.

EPICS CONTROL SYSTEM

A distributed field control system is also developed to control and monitor the solenoid current, magnetic current, vacuum level and water temperature in real time.

CONCLUSION AND OUTLOOK

Currently, a comprehensive timing and synchronization system is developed in TTX project with measured rms electron bunch arrival time of 540fs. Table 1 concludes the overall performance of the synchronization system.

Low level RF control would be the next step towards better synchronization performance.

Table 1: System Parameters and Measurement Results

Electron bunch parameters	**Font**	**Space After**
Repetition Rate	10	Hz
Laser injection phase	17.1	Deg
Electron bunch charge	1.6	pC
RMS Electron bunch length	970±70	Fs
Electron bunch size	0.80	Mm
Laser-RF rms timing jitter	92±40	fs
Electron bunch rms arriving jitter	540±30	fs

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