Long-term stable fiber–based picoseconds optical synchronization system in SG-II

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A fiber-based precision synchronization triggering system using fiber pulse stacker combined with high-speed electronics processing technology is presented. The relative timing jitter between two laser pulses achieved with this system is 4.09 ps (rms) in 2 h. The impact of the optical pulse amplitude fluctuation on the timing jitter is effectively reduced by high-speed analog-digital conversion and the reliability of the synchronization measurement system is confirmed.

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Accurate and stable time control of laser pulses is a significant technology in high power laser systems such as SG-II, NIF, and OMEGA, because it has a great influence on the system reliability and accuracy. Timing jitter on the order of 10 ps (rms) is required in many physical experiments and subsystems of the laser systems. For example, the optical parametric chirped-pulse amplification (OPCPA) requires robust synchronization between pump pulses and seed pulses in order to ensure the overlap of the two pulses on the nonlinear crystal and the realization of effective and stable amplification[1,2]. Similarly, the timing jitter between the pre-pulses and the main pulses should be extremely low in the experiment of study on X-ray united driving of the long and short pulse lasers to guarantee the reliability of experimental results[3]. In addition, the precision synchronization triggering is needed in many subsystems of the large laser system, such as the triggering of the streak camera in the measurement subsystem and so on.

Various techniques for precision optical pulses synchronization have been proposed and demonstrated, such as homologous laser pulses stacker[4], homologous triggering signals[5], producing triggering signal with Si-photoconductive switch[6], and so on. Producing high-quality electrical triggerring signals to synchronize uncorrelated laser systems[6−8] is a flexible and easy-to-expand synchronization scheme. Using fiber pulse stacker combined with high-speed electronics processing technology, we have developed a fiber-based precision synchronization triggering system for SG-II, which is compact, high accuracy, and long term stable. The relative timing jitter between two optical pulses achieved with this system is 4.09 ps (rms) in 2 h, which has met the high-precision synchronization acquirements of SG-II and reached the international advanced level.

To achieve the accurate and stable trigger, the electric triggering signal must meet the following requirements: the time jitter between the triggering signal and the laser pulses should be low to avoid the additional time jitter; the rise edge of the triggering signal should be steep to ensure the stability of the trigger time; the triggering signal should have sufficient amplitude and time width to make sure the effective trigger. A precision synchronization triggering system is demonstrated to meet the above requirements, as shown in Fig. 1.

In order to meet the requirement of time width of the trigger signal, we use a pulse stacker to lengthen pulse. As shown in Fig. 2, the hundred-picosecond short pulse can be lengthened to nanoseconds through multiple times of splitting and combining with time delays using a series 2×2 fiber couplers. The stacked pulse is then high-fidelity converted to an electrical signal by the optical-electrical converter, which has a rapidly rising edge. Additionally, an ultrafast comparator is used to realized the analog-to-digital A/D conversion for three objectives: to eliminate the disorderly part on the top of stacked pulse caused by interference effects between the short pulses; to reduce the impact of the optical pulse amplitude fluctuation on the timing jitter; to stabilize and limit the amplitude of triggering signal protecting following devices from damage. At last, the output pulse of the comparator is amplified by an ultrafast amplifier to obtain sufficient amplitude. All the electronic components have bandwidths wide enough to ensure the fast rise time. The high quality trigger signal achieve with this scheme can be used for precision triggering of laser system or instruments mentioned above.

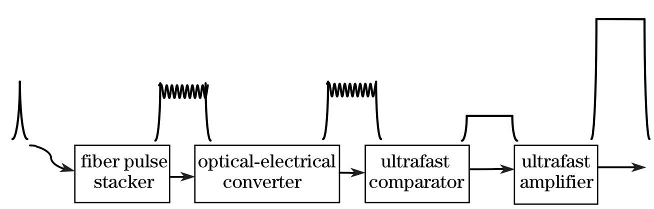

Fig. 1. Schematic diagram of the synchronization triggering system.

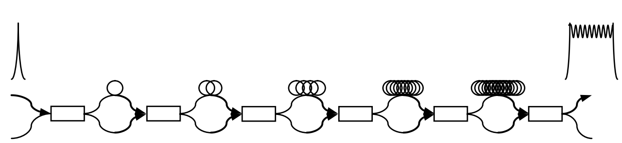

Fig. 2. Schematic diagram of the pulse stacker.

The synchronization triggering system has been used in the SG-II laser system in the synchronization between 30/80-ps short pulses and nanoseconds chopping laser pulses and the OPCPA laser system which are with similar jitter acquirements. The synchronization between 30/80-ps short pulses and nanoseconds chopping laser pulses is realized as shown in Fig. 3.

The mode-lock laser (GE-100) provides pulses with 80 or 30-ps pulse width as the seeds of SG-II. A part of the output pulse of the mode-lock laser is conditioned by

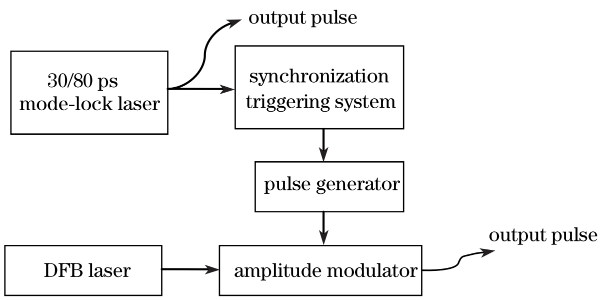

Fig. 3. Synchronization between the short pulses and the nanoseconds pulses.

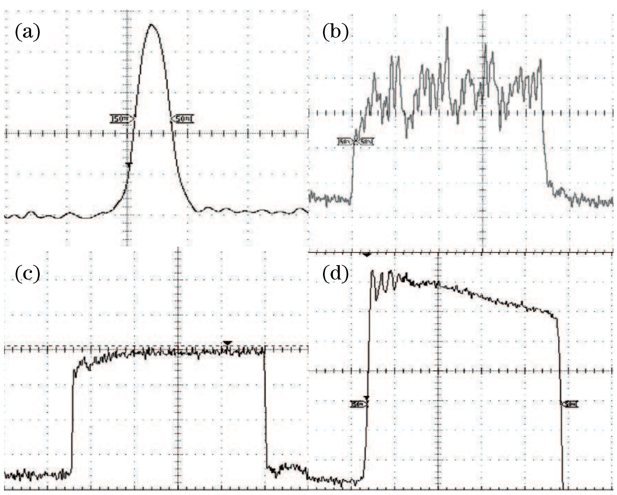

Fig. 4. Processing of trigger signal. (a) 80-ps mode-lock pulse; (b) stacked pulse; (c) output of the comparator; (d) trigger signal.

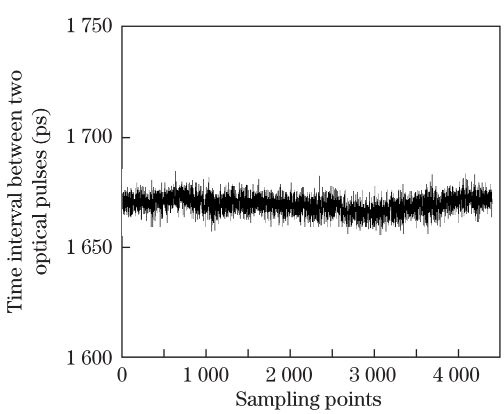

Fig. 5. Time interval between two optical pulses.

the synchronization triggering system to produce a trigger signal for the pulse generator of the chopping laser pulses. Therefore, the nanoseconds laser pulses chopped from the output of DFB laser with the amplitude modulator driven by the pulse generator is synchronized with the output of the mode-lock laser. The bandwidth of the optical-electrical converter used in the synchronization triggering system is chosen to be 1.2 GHz to make sure the rise time and fall time of the optical-electrical converted signal is always ~100 ps whenever the seed is 30 or 80 ps, so the fiber pulse stacker is universal for the different seeds.

Figure 4 shows the process from the mode-lock pulse to the trigger signal. The stacked pulse out from the fiber stacker is with 5.5-ns time width and with serious interference on the top, and the output pulse of the comparator is almost a square wave with the same time width and fast rise time of 35 ps. Ultimately, the rise time of the trigger signal is ~100 ps limited by the bandwidth of the amplifier and the amplitude is ~7 V which is enough for the effective trigger. The synchronization achieved with the trigger signal is measured using a fast optical-electrical converter (8 GHz) and the oscilloscope (12 GHz). The time jitter is 4.09 ps (rms) in 2 h.

As shown in Fig. 5, the time jitter between two optical pulses is extremely low and stable, at the same time no thermal drift is observed. The long-term stable synchronization is mainly due to the compact all-fiber structure, the fast A/D convertor and the stable electric circuit design.

Two homologous optical pulses are used to test the measurement limit of the measurement system and to confirm the reliability of the measurement results. The time jitter between the two homologous optical pulses is measured to be 3.58 ps (rms), which can be identified as measurement limit. That means the measurement result of time jitter larger than 3.5 ps is reliable.

The impact of the optical pulse amplitude fluctuation on the timing jitter is investigated. As the input optical pulse is attenuated to half (the stability of the optical pulse amplitude in front end of SG-II is less than 2% (rms) by ordinary), the time-interval between the synchronized pulses changes for 20 ps which is comparable to the time jitter (p-p) and is extremely low. The impact of the optical pulse amplitude fluctuation can be completely eliminated by an active feedback control module in the future work.

In conclusion, we present a precision synchronization triggering system, which is compact, stable, and easy to operate. The synchronization triggering system is used in SG-II OPCPA laser system and united driving of the long and short pulse lasers for physical experiment. Its performance will be further enhanced in the next step.

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