SYNCHRONIZATION OF A PHOTO-INJECTOR AND A HIGH POWER LASER WITH INDEPENDENT CLOCKS

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Abstract

The plasma acceleration project ESCULAP (ElectronS CoUrts pour L'Accélération Plasma) aims at studying electrons injection into a laser plasma accelerator. This requires the injection of short electron bunches generated by the photo injector PHIL (Photo injector at LAL) into a plasma wave by the high power femtosecond Laser LASERIX. As a first step we have studied how to synchronize PHIL and LASERIX. As these two machines had not been initially designed to work together, simple synchronization solutions were not available. We detail here the synchronisation scheme that we have tested and the experimental results obtained.

INTRODUCTION

In the ESCULAP (ElectronS CoUrts pour L'Accélération Plasma) project [1] short electron bunches from the photo injector PHIL will be injected in a plasma and accelerated in the wake created by high-power laser pulses coming from the laser LASERIX. To perform such experiment a synchronisation between the two machines is required and this is complicated by the fact that the two machines have been built independently and without such application in mind.

PHIL

PHIL is a photoinjector accelerating electrons up to 5 MeV[1] . It has been extensively described in [2]. The electrons are accelerated in a 2.5 cells RF-Gun with a resonance frequency of 2.998 55 GHz.The 3 GHz RF is generated using a ×40 Phase Locked Loop (PLL) from an ultra-stable ($\Delta f / f = 10^{-9}$) quartz operating at 74.963 750 MHz (75 MHz). The same quartz is also used to phase lock the oscillator of a ps laser [HQ laser picoREGEN] used to generate electron bunches. Timing signals, based on a 75 MHz counter and synchronized with the 50 Hz line signal, provide the 5 Hz repetition rate for PHIL experiment. One Timing signal is used to generate the 3.5 µs RF power pulse injected in the RF gun. Another one drives the gate that selects the optical pulse in the ps laser oscillator. This ps laser pulse is amplified and frequency quadrupled to provide a 7 ps and 50 µJ UV pulse. The electron beam is then generated by the copper cathode of the RF GUN irradiated by the UV laser pulse. The time jitter measured with a 40 ps rise time photodiode between the RF signal coming from the RF cells through a RF picker and the UV laser pulse converted, has a value of around 1.2 ps rms (cf Fig. 1) for a 3 min acquisition time with a Lecroy 760zi oscilloscope. This measurement gives us a reference to benchmark the performances using another laser. The presence of LASERIX nearby the electron accelerator PHIL gives us the opportunity to use the femtosecond UV laser pulse form LASERIX, in place of the ps laser pulse, to generate sub ps electron bunches needed for laser plasma acceleration. LASERIX has to be synchronized with the radiofrequency of the electron gun cavity of the accelerator within picosecond resolution .

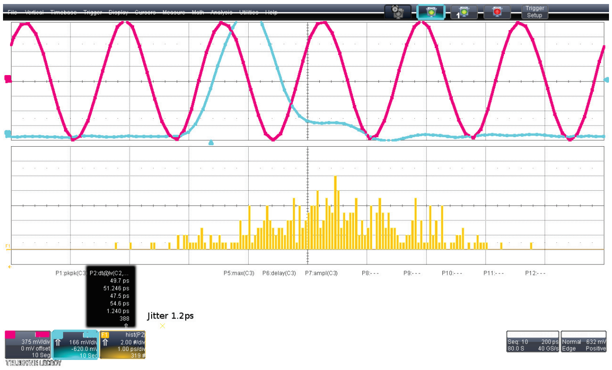

Figure 1: Jitter measurement between the ps laser pulse and the 3 GHz RF of PHIL.

LASERIX

LASERIX is a CPA laser chain which delivers laser pulses of 35 fs duration at 815 nm with energy up to 2 J at 10 Hz frequency rate. Its design is based on [3]. This laser chain is mainly used to generate XUV laser radiation [4] for pump probe experiments.The following section explains briefly the operation of the front-end in order to understand the syn-

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[1] An upgrade is underway to bring that energy to 10 MeV.

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chronization scheme developed in this paper. The front-end is constituted of a laser oscillator (femtolasers) which delivers a train pulses at an adjustable frequency around 75 MHz with few nJ energy per pulse. Those pulse trains go through a booster amplifier in which a triggered pulse picker first selects pulses at 10 Hz repetition rate thanks to Pockels cells and then amplifies the energy up to few μJ.The beam is then temporally stretched and amplified up to 30 mJ. A fraction of this beam, used for the electrons generation, is compressed to 50 fs and the third harmonic is generated to get finally 90 μJ. The frequency of the train laser pulses at the output of the laser oscillator can be controlled by a positioner (SmarAct SLC 2790 series) which controls the position of the cavity end mirror with 1 nm resolution but doesn't allow the phase control of the train pulses with respect to an external oscillator. The train laser pulses is detected by a photodiode inside the oscillator and the repetition rate is monitored by a frequency counter (Keysight 53230A) and a numerical feedback is used to maintain the frequency at a given value. A delay generator (genpulse, from the company Amplitude Lasers) is used to distribute a trigger signal and synchronizes all the laser chain. An external 10 Hz TTL signal can be used to trigger this delay generator. This delay generator will trigger the pulse picker. Note that, due to the pump laser, a 600 μs lag time between the 10 Hz TTL signal and the pulse picker has to be respected.

METHOD

As the two machine clocks are independent, the trigger must operate in such way as to find a fixed phase relation between the two clocks. This is done by using a RF mixer and low-pass filtering the output to keep only the heterodyne frequency. By using a comparator to always detect the same phase (for example positive zero crossing) of this heterodyne frequency one can generate a trigger signal that has a fixed phase relation with the two RF clocks (see Figure 2). The signal coming from a fast photodiode in the laser oscillator filtered is sent through a PLL to multiply the frequency by 40 to get finally 3 GHz signal synchronized with the laser pulse train a mixed (mixer M63C) with the 3 GHz RF coming from PHIL. To stabilize the LASERIX oscillator repetition rate, the output signal of the mixer is sent to the frequency counter. This measurement is sent to the LASERIX oscillator frequency feedback to achieve a stabilization of the heterodyne frequency at 2 kHz. A SRS delay generator is triggered from this zero crossing and generates a 20 Hz TTL sent to a delay generator (Master Clock, Thales Laser) which generates itself the TTL triggers to LASERIX (10 Hz) and PHIL (5 Hz) timing distribution systems.

RESULTS

The jitter between the 3 GHz coming from the PHIL pilot and the laser pulse has been characterized with an oscilloscope (Lecroy 760 Zi,40 Gsapmles/s). The laser pulse was detected with a 40 ps rise time photodiode. The jitter is measured to 1.3 ps rms after 1800 shots (3 min) represented on Figure 3.b. We observe that the delay between the laser pulse and the RF of the PHIL pilot drifts at a rate around 10 ps/hour shown on Figure 3.a. This long term drift is attributed to thermal fluctuation over the day. The synchronisation signals have to cross different parts of the building, not all stabilised in temperature, over tens of meters. To achieve the ps jitter regime on few minutes, two basic points in the synchronisation scheme proposed on Figure 2 need to be emphasized. The first one is the noise at the output of the mixer which induces a jitter on the zero crossing detection and as a consequence a jitter between the laser pulse and the 3 GHz RF gun. We first have tried to mix directly the 75 MHz signals from the oscillators and a lower limit of the jitter of 7 ps for only 1200 shots (2 min) has been observed. The PLL which multiply by 40 the frequencies before the mixer increases the sensitivity to the difference of phase between the two oscillators and, as a consequence, reduces the effect of the mixer output noise. The second basic point which has to be highlighted is the stabilization of the laser oscillator 75 MHz frequency. The synchronisation scheme on Figure 2 is used to send an external 10 Hz TTL trigger signal to the laser chain. Due to the 600 μs lag time described before, the laser pulse amplified and sent to the photocathode is not that one which is coincident with the zero crossing rising edge of the heterodyne signal. A fluctuation of the 75 MHz LASERIX oscillator frequency will induce a fluctuation of the heterodyne frequency that impinges a fluctuation of the delay between the laser pulse and the RF of PHIL. A drift of 0.15 Hz of the 75 MHz LASERIX oscillator frequency will induce a jitter of 1 ps. Thus, to reach this 1 ps jitter regime, it is necessary to control the 75 MHz LASERIX frequency with a resolution better than 2×10^{-9} and this shows that the stabilisation of the 75 MHz laser oscillator frequency is crucial. We have first tried to stabilise directly the repetition rate of the laser oscillator with the frequency counter at 75 MHz, represented in dashed line on Figure 2 and have obtained a jitter at least 4 ps rms. This result shows it is impossible to reach the mandatory LASERIX oscillator stability by controling directly the 75 MHz with the frequency counter and the feedback control. In the actual synchronization method, the stabilisation of the 75 MHz LASERIX frequency is insured by the measurement of the heterodyne frequency at 2 kHz. This frequency can be easily measured at the Hz resolution. Furthermore, thanks to the frequency multiplication by 40 with the PLL, a stabilization of the heterodyne frequency at 5 Hz resolution insures the stabilization of the 75 MHz laser oscillator frequency at 0.15 Hz resolution.

CONCLUSION

A synchronisation scheme of the CPA laser chain LASERIX with the electron accelerator PHIL has been demonstrated and a jitter between the laser pulse and the RF of the accelerator of 1.3 ps rms over few minutes has been measured. The long term stability is limited by a slow drift due to thermal fluctuation during the day. In the solution proposed in this paper, the laser oscillator doesn't need to be

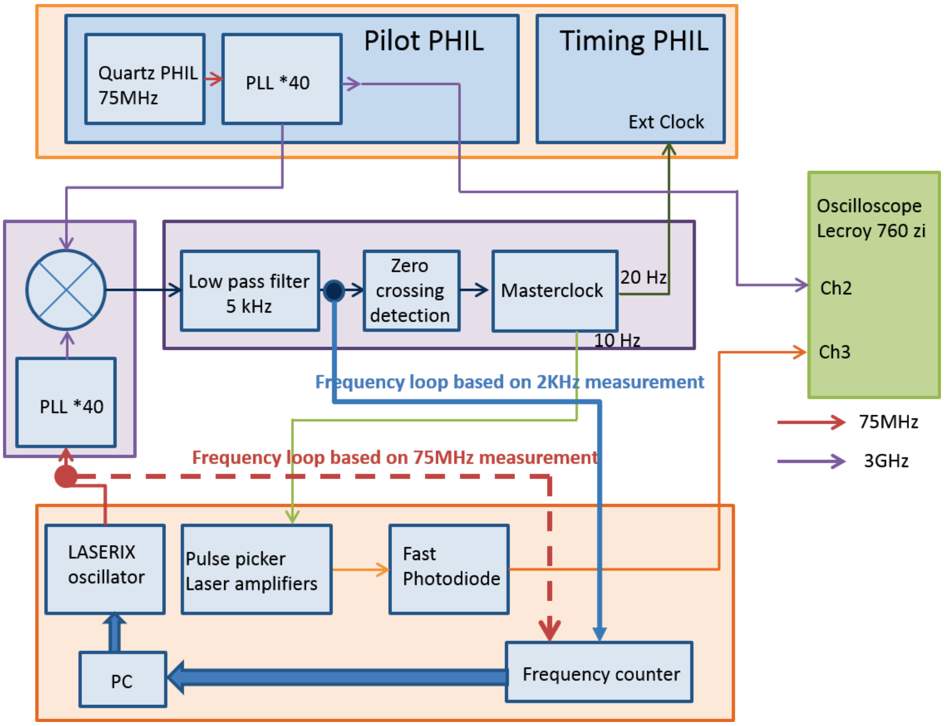

Figure 2: At bottom of the figures is represented the synchronisation of LASERIX, at the top the synchronisation of PHIL and at the middle the mixer used to synchronized the two facilities. After the mixer, a zero crossing detection and the masterclock are used to generate the triggers for LASERIX and PHIL.

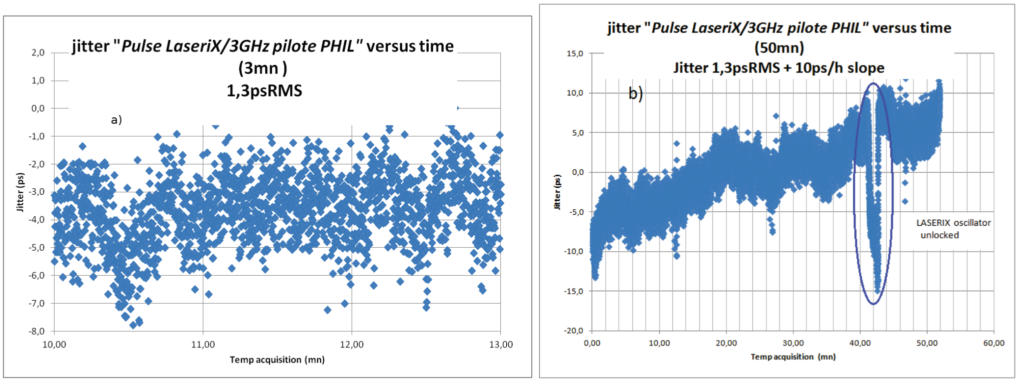

Figure 3: Both figures represent the jitter between the UV laser pulse and the 3 GHz from the PHIL pilot. On Figure 3a), the data are recorded during 50 min. On Figure 3 b) the data are recorded during 3 min. A gap in the delay is observed and was due to a safety stop of the frequency feedback.

phase locked with the quartz oscillator of the accelerator's pilot but just need to be stabilized in frequency. The long term drift can be stabilized in the PHIL pilot which provides phase shifters for the RF 3 GHz. To improve the short term jitter we expect to be able to reduce the phase noise of the laser oscillator partly due to the steppers noise used to control the 75 MHz LASERIX frequency oscillator. We plane to replace it by an analogical one. We expect also to reduce the jitter by decreasing as much as possible the 600 µs lag time.

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