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CTF3 photoinjector: RF synchronisation of the laser system

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Abstract

In this report, the status of the synchronization system between the CTF3 photoinjector laser chain and the RF reference signal which drives the photoinjector gun and accelerates the electron bunches is described. Measurements of the relative time jitter between the RF and laser systems are found to be below the value required for CTF3 operation.

1. Introduction

After the delivery of the laser system components from RAL to CERN, and after initial setting-up of the system, a number of hardware problems were encountered. In particular, recurrent problems with the synchronization between the laser the external RF reference signal at 1.5 GHz were observed.
Detailed observations in summer 2008 showed that, while it was possible to synchronize the laser oscillator to the external RF reference signal, synchronization was lost within a few minutes after switching on the laser pre-amplifier.
In this report, a brief overview of the CTF3 laser system is provided. A detailed description of the oscillator and the synchronization unit is provided. The problems and the solution found are described, and a summary of the time jitter measurements done at CERN is given.

2. The CTF3 photoinjector laser system

The photoinjector laser system designed to produce the CTF3 drive beam is described in this chapter. A schematic layout is given in Figure 1. Further details can be found in Refs. [1-5].
A customary made Nd:YLF oscillator (High Q Laser Production GmbH[1] model *pico*TRAIN IC-1047-1000-ps Nd:YLF 1.5 GHz Sync) produces vertically polarized pulses at a repetition rate of 1.5 GHz (666.667 ps between two consecutive pulses) with an average power of P~300 mW, a central wavelength $\lambda \sim 1047$ nm and with a pulse time width of $\tau \tilde{} 6$ ps. These pulses are first amplified by a Nd:YLF "pre-amplifier" required to increase the average power up to P~10 W. This pre-amplifier is built by High Q Laser as well as the oscillator. The pulses delivered by the pre-amplifier have the same characteristics (τ~6 ps (FWHM) and $\lambda \sim 1047$ nm). In between the oscillator and the preamplifier a dedicated device called "Phase Coding" will be placed. This equipment provides a special temporal distribution of the pulses necessary to produce electron bunches as required for the CTF3 delay loop. After these first stages, the laser beam is injected sequentially into two powerful Nd:YLF amplifiers: the first one is made up of a L_1 = 80 mm long Nd:YLF rod with d_1 = 7 mm diameter aperture pumped by 5 stacks of diode lasers symmetrically arranged around the rod.

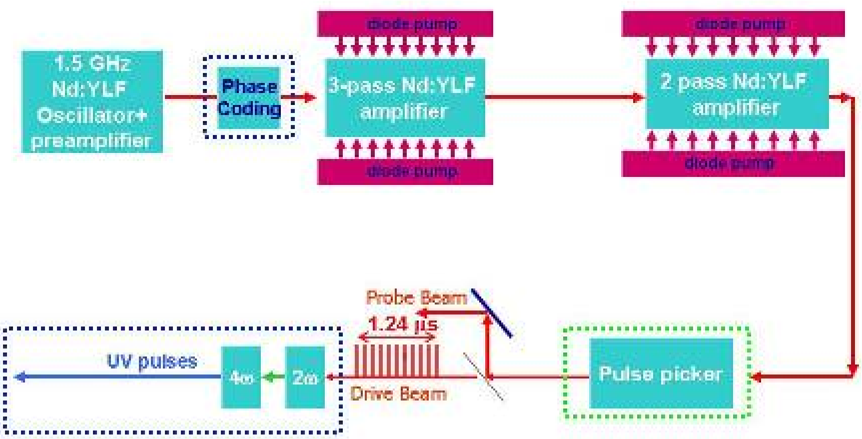

Figure 1: CTF3 photoinjector laser system

[1] High Q Laser Production GmbH, Kaiser-Franz-Josef-STR.61 A-6845 Hohenems Austria, http://www.highqlaser.com

The total diode pump peak power is 15 kW and its amplification window is τ_1~ 400 μs. The second amplifier has a rod length L_2 = 120 mm and diameter d_2 = 10 mm; it is pumped by 5 diode arrays symmetrically arranged around the rod, the pumping peak power is 17 kW and its amplification window is τ_2~200 μs. This amplification starts with a delay of 200 μs w.r.t. the starting time of the first amplifier. Both amplifiers are designed to work at a repetition rate in the range of up to 50 Hz.
After the second amplifier, a Pockels cell ("pulse picker" in Figure 1) allows to select the pulse train length, according to the requirements of the CTF3 RF gun. Ultimately, the CTF3 drive beam will require a 1.272 μs long train of pulses at 1.5 GHz, with a repetition rate of up to 50 Hz. Presently, a repetition rate of 1-5 Hz is being used.

3. The oscillator and the synchronization unit

The mode-locked laser oscillator has a resonator of approximately 10 cm. In a free-running mode it generates pulses at the pulse repetition rate of approximately 1.5 GHz. The application of the laser in the CTF3 photoinjector requires its synchronization within less than 1 ps with a fixed frequency of an RF-field generated by the klystron of the electron gun. Therefore, the external synchronization option was a part of the order placed at High Q Laser. Consequently, a specially designed module Sync-HQL has been implemented into the laser oscillator.
Its functioning is described in the laser manual: "Synchronization is achieved by putting the one laser resonator mirror on a voltage controlled piezo. The voltage applied to the piezo changes the cavity length and thus the mode-locked pulse repetition rate. In a feed back loop, the pulse repetition rate is controlled and adjusted until the pulse frequency is locked to an externally provided frequency reference signal. In addition to this fast and fine cavity length control, a slow microprocessor-controlled stepping mechanism provides coarse cavity length control. The heart of the HighQ laser synchronization unit is a phase detector circuit which converts the phase between the frequency reference and the laser pulse train signal into a voltage signal. This phase detector output carries the information about the temporal deviation between the reference signal and the laser pulse train. Based on the phase detector output, a feedback circuit controls the length of the laser resonator until synchronization is achieved. To provide the synchronization on a short time scale (several 10 kHz to Hz frequency regime), the piezo holds one of the laser cavity mirrors at the required position and thereby controls the cavity length within a few microns. On a longer time scale (second to hours) a second processor unit controls the position of the laser cavity mirror on a coarse scale and changes the cavity stepwise whenever the piezo reaches its limit (~50KHz on each side with respect to the central position)." End of Quotation.

Initial observations of synchronization problems seemed to point to some optical perturbation, possibly laser radiation coming back from the preamplifier and giving rise to noise in the electronic signal sent to the synchronization unit. Such noise could make it impossible for the piezo drive within its range of movement to keep the system in phase, and as a consequence the synchronization could be lost. Given the layout of the laser chain design, such problems were anticipated - therefore, from the design phase, a Faraday optical isolator was placed between the oscillator and the preamplifier to avoid any back reflection that could give rise to this kind of noise. The perturbations of the electronic signal controlled by the spectrum analyzer that were seen when the preamplifier was switched on led to the proposal of placing a second Faraday isolator just after the first one, in front of the preamplifier - any remaining back reflection is now completely suppressed. Once the second Faraday isolator has been placed in series to the first one, together with a wave plate (λ/2) to properly match the polarization, we observed the following: When the preamplifier was switched on, no electronics signal noise could be detected in the spectrum analyzer - nevertheless, synchronization was lost again after some minutes.

After several other trials, we concluded that problems rising from instabilities of the cavity due to thermal effects could not be excluded. At this point, we decided to call in the High Q Laser experts for a thorough analysis of the oscillator. During the visit of the expert, it was found that the semiconductor saturable absorber mirror (SESAM) used as the end cavity mirror of the oscillator had wrong settings. The layers of the SESAM mirror should be heated or cooled depending on the application. In our case, the layers should be Peltier-heated to 50^o C. After some tests by the HighQ expert it was found that the software settings which control this heating were wrong and that the layers were left at room temperature. As a result, the cavity was in an unstable configuration. This instability made it apparently possible to synchronize the oscillator when the preamplifier was off, but not possible when the preamplifier was on.
Once the settings for the heating of the layers in this mirror were corrected, and the oscillator cavity re-aligned, the synchronization of the laser oscillator with the RF worked without problems.
Since this intervention on the oscillator in September 2008, the laser - RF synchronization has been scrutinized every day and has been found to be stable.

4. Synchronization time-jitter measurement

4.1 HighQ jitter data

The HighQ synchronization unit provides a "time-jitter" output, which can be recorded over time. A typical trace recorded during a normal working day is shown in Figure 2. The zero time correspond to ~9:00 am the last point to ~06:00 pm and a jitter value is recorded every second. Standard operating conditions of the laser system were applied: oscillator diode current 1.55 A, preamplifier diode current 39 A and first amplifier diode current 90 A. The second amplifier was not running during this measurement period, but it was later found that the operation of the second amplifier has no detrimental impact on the synchronization.

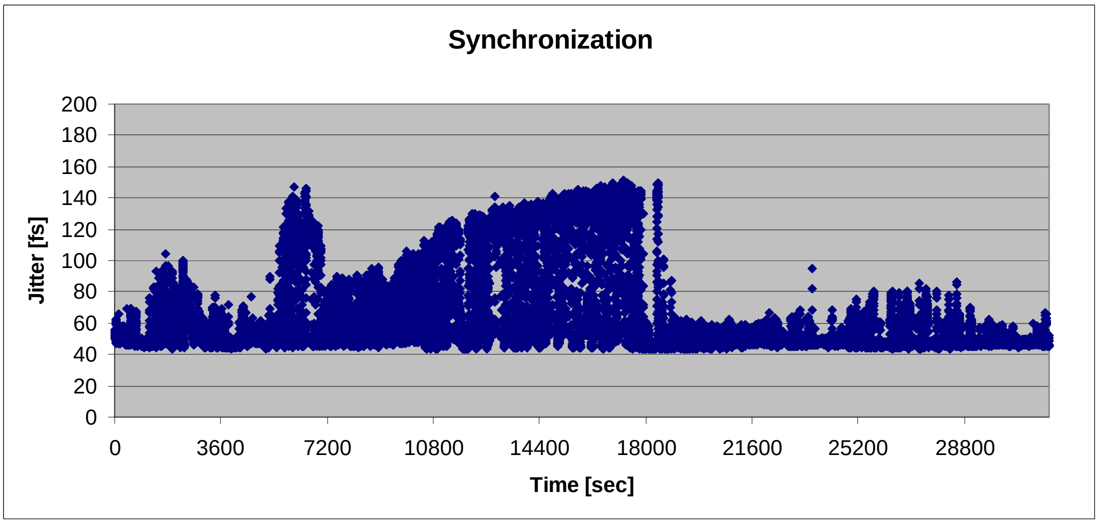

Figure 2: Time-jitter information as provided on the HighQ synchronization unit

4.2 CERN time-jitter measurements

In order to have a cross-check with the HighQ time-jitter information, we have used a LeCroy SDA 18000 (Serial Data Analyzer) in RIS mode (sampling scope).

In a first step, the amplified laser pulses at a repetition rate of ~1.5 GHz have been coupled via an optical fiber to a New Focus 25 GHz photo-detector. The output signal from this detector has been connected to the first channel of the SDA (which, in RIS mode, has a bandwidth of 6 GHz). Using the "period@level" feature of the SDA software, the intrinsic jitter in the laser pluse train (time-jitter from micropulse to micropulse) has been measured.

The "period@level" feature measures the period at a specified level and slope for every cycle in a waveform. The histogram shown in Figure 3 is a screen-shot of the LeCoy SDA and gives the numerical results of the measurement in the third column. The mean value the period is 666.99 ps (nominal 666.667 ps), and the standard deviation obtained from 26447 micropulses is 345 fs. This intra-train jitter is very close to the fundamental limit of the LeCroy SDA itself (given as ≤ 350 fs in the documentation). We conclude that the RIS operating mode is the correct one for the laser-RF time jitter measurement.

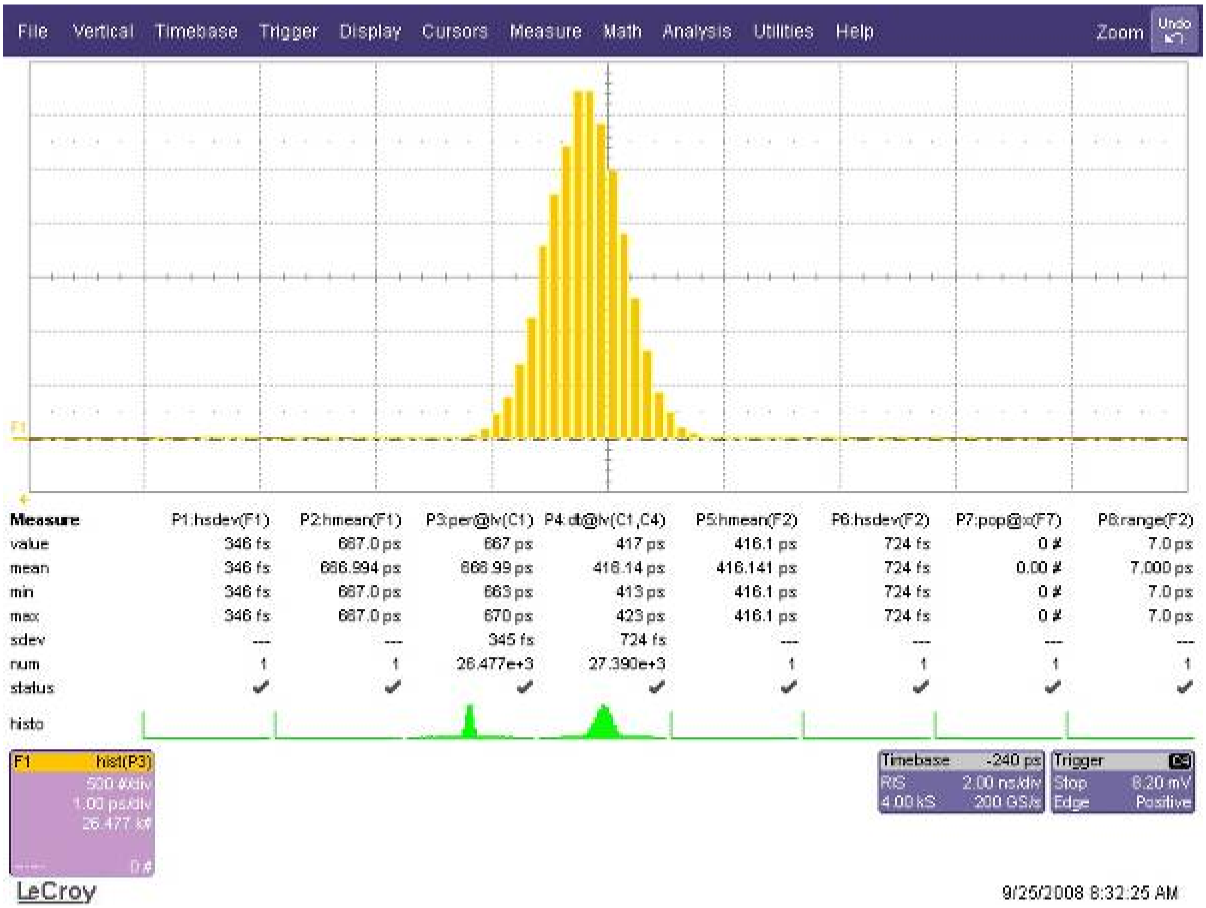

Figure 3: Intra-train time-jitter measurement using the LeCroy SDA 18000.

In a second step, the RF reference signal has been connected to the fourth channel of the LeCroy SDA and has been used as trigger for the instrument. Using the feature "dt@level", the time-jitter between this RF signal and the laser signal connected to the first channel has been measured. The "dt@level" feature gives the time of the "source 2" edge minus the time

of the “source 1” edge; it computes the time between transition of a fixed level of 2 sources or between a trigger signal and a transition of a level of a single source.
The result is shown in Figure 4. The values shown in the 4th column under the histogram provide an analysis of the measurement. The standard deviation from 27390 measurements is found to be 724 fs. Note that this includes the intrinsic properties of the LeCroy SDA.

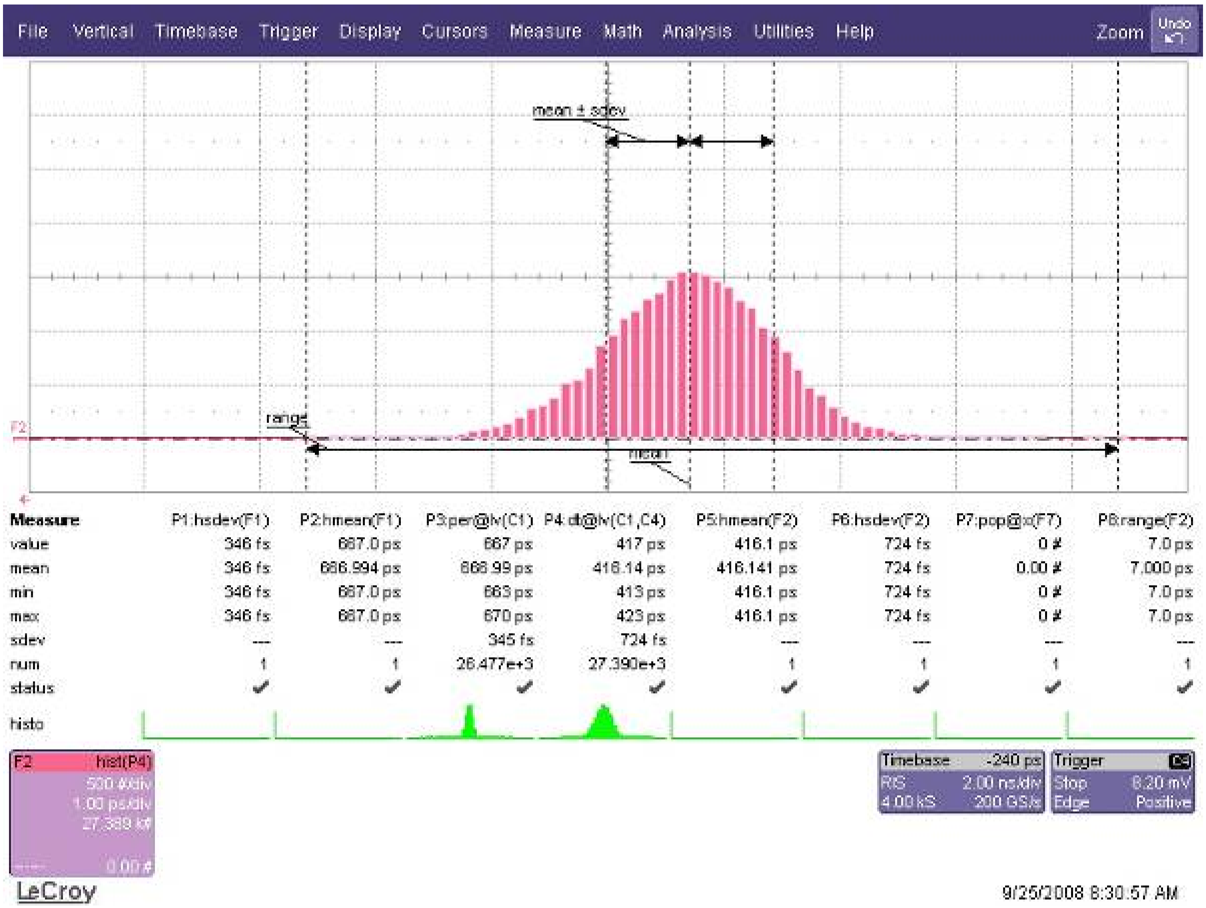

Figure 4: Laser-RF time-jitter measurement using the LeCroy SDA 18000.

The jitter noise floor (JNF) of the Le Croy SDA, i.e. an intrinsic noise contribution to any jitter measurement by this instrument, is ≤ 350 fs. Therefore, the real intrinsic jitter of the laser signal with respect to the RF reference signal is retrieved from the following equation:

$$J_{real} = \sqrt{(J_{meas})^2 - (JNF)^2}$$

As a result, the time-jitter measured with this method is found to be J_{real} ~ 634 fs, better than the 1 ps jitter specified for the PHIN photoinjector laser system.

6. Summary

The laser oscillator has been controlled and analyzed in collaboration with manufacturer (High Q Laser) experts. This investigation led us to the conclusion that the settings for the end mirror of the cavity were outside the nominal values, placing the cavity in a unstable configuration.

Once these settings have been corrected, the oscillator cavity started working properly and the synchronization started to be stable for many days, with a time-jitter better than specified in the PHIN project proposal.

Acknowledgements

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References

1) M. Petrarca, V. Fedosseev, N. Lebas "*CTF3 photoinjector laser amplifier construction*" CARE-Report-2008-012-PHIN
2) M. Divall et al., "*Design and testing of amplifiers for the CTF3 photoinjector laser*", CARE-Report-06-021-PHIN
3) I. N. Ross and M. Csatari, CLF Annual Report 2001/2002 202-205 (2002)
4) I.N.Ross, M.Csatari and S.Hutchins, '*High performance diode pumped Nd:YLF amplifier*', Appl. Opt. **42**, 1040-1047, (2003).
5) Y. Tang *et al*., CLF Annual Report 2004/2005.