DRIVE LASER SYSTEM FOR SPARC PHOTOINJECTOR*

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Abstract

In this paper we report the progress of the SPARC photoinjector laser system. In the high brightness photoinjector the quality of the electron beam is directly related to the photocathode drive laser. In fact the 3D distribution of the electron beam is determined by the incoming laser pulse. The SPARC laser is a 10 Hz frequency-tripled TW-class Ti:Sa commercial system. To achieve the required flat top temporal shape we perform a manipulation of the laser spectrum in the fundamental wavelength and in the third harmonic. The optical transfer-line has been implemented to limit the pointing instabilities and to preserve to the cathode the temporal and spatial features of the laser pulse. We present the recorded performances in terms of time pulse shape and rf-to-laser synchronization.

INTRODUCTION

The SPARC project is an R&D photo-injector facility at LNF-INFN, devoted to the production of high brightness electron beam at 150 MeV for a SASE-FEL experiment at 500 nm [1]. SPARC will allow also investigations into the physics of ultra-short beams, plasma wave acceleration, and X-ray Compton back-scattering.

Specs on SPARC laser system were fixed within the phase of the machine design. The goal is to provide photo-injector (RF-gun) with a proper laser pulse between 5 and 12 ps, able to generate an electron beam with a normalized transverse emittance less than 2 mm-mrad and a current of 100 A. We currently use a Cu cathode with a quantum efficiency of $2 \cdot 10^{-4}$ at 120 MV/m [2] therefore it is required about 50 μJ at 266 nm to extract 1 nC.

Challenging requests are made on laser temporal pulse profile (flat top pulse with 1 ps rise time and ripples limited to 30%) to minimize the e-beam emittance; a pulse shaping activity is in progress and some results have been presented [3, 4]. In the following we first describe the laser system and then we report the measured performances in term of temporal pulse shape and laser to radio frequency (RF) time jitter.

LASER SYSTEM

The SPARC laser is a TW-class Ti:Sapphire system produced by Coherent. The laser consists of a Ti:Sa oscillator that generates 100 fs, 12 nm pulses. The oscillator operates at a repetition rate of 79+1/3 MHz corresponding to the 36th of the RF frequency. An acousto-optic programmable filter called "DAZZLER," [3] upstream the amplifier, is used to modify the laser spectrum in order to obtain the target temporal profile[5].

The laser amplification process is carried out by one regenerative pre-amplifier pumped by 10 W Nd:YLF laser and a two double passes stages which are excited by the second harmonic of a Nd:YAG with an energy of 0.5 J per pulse. The system delivers pulses at λ=800 nm with energy of about 50 mJ and a repetition rate of 10 Hz.

At the output of the amplifier the IR pulses is sent to a third harmonic generator, where UV pulses hundreds fs long with an energy of up to 3 mJ are produced. The up-conversion is required to generate photon with energy larger than the work function of the photocathode. The third harmonic generator consists of two type I beta barium borate (BBO) crystals of 0.5 and 0.3 mm: the harmonic generator produces first the second harmonic signal and then the third harmonic signal, at λ=266 nm, by frequency sum.

The harmonic generation is followed by an UV stretcher to lengthen the pulse up to 15 ps. An optical transfer line is used to image the beam onto the cathode.

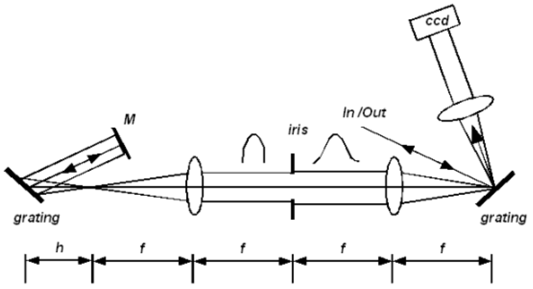

Figure 1: Layout of the UV stretcher.

TWO STAGES PULSE SHAPING

Previous measurements showed that the achievable rise time in the UV using the DAZZLER is too long: about 3 ps [3]. In fact, due to the finite bandwidth of the non-linear crystals, the steepness of the rise and fall time of the resulting flat-top pulses can not be fully controlled by the DAZZLER. A second result we found is that, after the UV stretcher, due to the applied large chirp, there is a full correspondence between spectral and temporal pulse profiles. This observation suggests that to improve the rise time the spectral tail has to be sharply clipped. To perform this manipulation we modified the UV stretcher to have a spatial dispersion of the wavelengths.

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The modified stretcher is a particular version of the 4f optical scheme with two gratings and two lenses as shown in Fig. 1 [4]. A collimated beam is sent onto a diffraction grating having 4350 lines/mm at an incidence angle of 43°. The dispersed wavelengths are then focused using f=500mm lens located at a distance f from the grating.

On the lens focal plane each spectral component will reach a focus in a different spot. In other words on this plane (henceforth named Fourier plane) there is full correlation between wavelength and transverse position. This allows any desired, high-resolution, amplitude modulation on the spectrum simply placing a filter or mask at this plane. The beam is then re-collimated by a second lens and sent to another grating which compared to a classical 4f system is shifted from the symmetry position by a distance h. The spectral components are then retro-reflected by the mirror M and retrace back their path through the system. The shift of the second grating produces an outgoing pulse length proportional to h.

In our UV pulse shaping after the second pass the fraction of the beam reflected by the grating is focalized by a 30 cm lens onto the plane of a CCD camera. In this way a high-resolution (≈ 0.005 nm) spectrometer is integrated in the shaping system.

Summarizing, the functions of the described optical system are: i) the change of the pulse length; ii) the spectral amplitude modulation; iii) the single shot measurement of the spectrum of the output pulse.

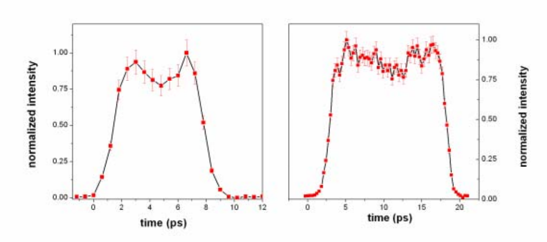

Figure 2: Cross-correlation measurement for a 6 ps and 15 ps UV pulse duration.

Cutting the spectral tails we observed a net reduction on the rise time. The temporal profile has been traced by a UV-IR cross-correlator [10]. In this device the UV pulse is gated by the amplified IR pulse. By changing the delay of the IR pulse it is possible to reconstruct the time intensity of the UV beam with a resolution depending on the duration of the gate pulse.

In the Fig. 2 we report two cross-correlation traces with the error bars, obtained for two distances h in the stretcher, in order to obtain the output pulse length of 6 ps and 15 ps FWHM. The rise time, in both cases, are about 1.8 ps slightly longer than the calculated value. In fact the cross-correlation has been measured using a relatively long IR gate pulse >1 ps. The long gate pulse induces an overestimation on the rise time. Including this effect the actual rise time is 1.4 ps. The described pulse shaping technique has been used to generate high brilliance e-beam, for more details [1].

The obtained rise time cannot be improved by increasing the steepness of the spectral cut. In fact, below 1.4 ps rise time, sharper cut causes overshoots in the time profile, without benefits in terms of rise time.

The overall efficiency of the shaper is limited to 20% due to the high diffraction losses of UV gratings the losses introduced by the filter. In our measure a pulse with energy of about 2 mJ is sent to the shaping system and the resulting output rectangular pulse has energy greater than 350 μJ.

It is important to stress the fact that the quality of the beam transverse profile is not affected by the cut of the spectral tails.

UV PULSE SHAPING

We show here that a Gaussian spectrum like the one naturally produced by the laser system is actually ideal if one aims at a flat-top longitudinal profile, thus removing the need of expensive and complex shaper systems in the IR. The simple idea at the basis of the described shaper is to eliminate the spectral tails of a natural spectrum of the lasers, by using an iris on the Fourier plane. Simulations show that a sharp cut of the spectrum induces overshoots in the temporal profile of the pulse, which could be used to balance the curvature of the Gaussian spectrum. In this simple way it would be possible to obtain a flat top laser pulse starting from a Gaussian-like spectrum.

Moving away from the Fourier plane the iris, one can also change the sharpness of the applied cut to adjust for the required curvature compensation. An optimal cut resolution is 0.05 nm that can be achieved by placing the iris 1 cm from the Fourier plane.

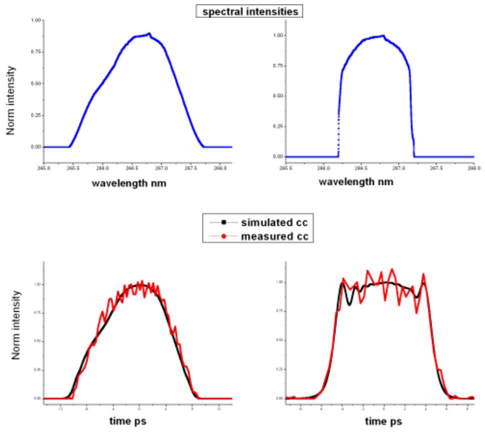

Figure 3: On the top Gaussian and cut spectra, and above the corresponding time intensity distributions measured (red) and calculated (black)

In Fig. 3, we report the experimental results obtained with this pulse shaper. On the left side we show the initial bell-shaped spectrum (blue curve) and the corresponding temporal profile measured with a cross-correlation (red curve). The black line represents the simulated cross-correlation obtained from the measured spectrum taking into account the chirp introduced by the stretcher and the finite length of the probe pulse. In the top-right corner we show the spectrum after the tails have been removed. Below we display the corresponding measured cross-correlation and the calculated one. The experimental cross-correlation presents ripples due to the pulse-to-pulse laser fluctuations. From these measurements we deduce two main results: 1) cutting the spectrum tails with the iris we measured a rise time of 1.55 ps. Since the cross-correlation has been obtained with a 750 fs long IR gate the real rise time is 1.4 ps comparable with the two stages pulse shaping 2) if the applied chirp is known, with a single shot measurement of the spectrum one can calculate with a good approximation the final temporal profile. Due to the wavelength filtering, the losses are 20 % larger respect to the two stages pulse shaping. This make the two stages pulse shaper more convenient.

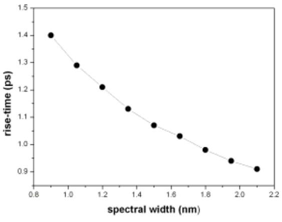

Figure 4: Rise time vs UV bandwidth.

In Fig. 4 we show the simulated rise time as function of the bandwidth of the spectrum. This simulation assumes that the chirp introduced by the stretcher has to be adjusted to maintain the same final pulse length (10 ps). For spectral bandwidth > 1.7 nm it is possible to obtain rise times < 1 ps. Further studies are going on to get this bandwidth by changing the harmonic crystals.

LASER TO RF SYNCHRONIZATION

A precise synchronization between the photocathode drive laser and the accelerating wave is necessary to have a fixed and stable time-of-arrival of the photons on the cathode with respect of the phase of the 2856 MHz RF field. This condition is very important to guarantee the stability and the shot-to-shot reproducibility of crucial beam parameters such as the beam charge, energy, emittance and energy spread. Beam dynamics simulations indicate a time jitter within ± 1 ps around the optimal phase is acceptable for the SPARC phase-1 experiment in order to limit the emittance growth to less than 10%.

To synchronize the laser respect to the RF clock the laser oscillator length is kept constant by an active feedback loop. This assures a stable repetition rate at 79+1/3 MHz which is the 36th sub-harmonic of the RF frequency. We measured at oscillator level, a time jitter characterized by a standard deviation of 350 fs [5].

To have information on the phase noise of the single laser UV pulse, we mix the signal comes from a RF cavity tuned at ¾ RF with the corresponding sub-harmonic of the RF master clock. The cavity was fed by a fast photodiode illuminated by the optical pulse. The photodetector is a bi-planar vacuum photodiode with of 100 ps a rise time operating at 2.5 kV bias voltage. The cavity grants an exponential decaying pseudo-sinusoidal signal with duration of about 1.5μs and allows a consistent relative phase measurement.

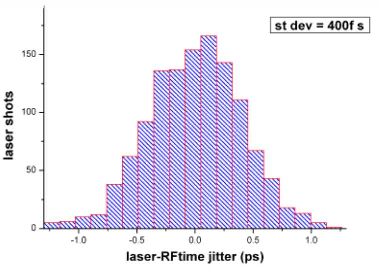

Figure 5: Relative phase between the UV pulse and the RF clock recorded over 2 minutes.

As reported in Fig 2 the time jitter standard deviation, recorded over few minutes, is about 400 fs [5]. This result is comparable to the jitter measured at the oscillator and indicates the amplifier contributes very little to the final phase noise. The good level of synchronization is confirmed by the stability of the e-beam parameters.

CONCLUSIONS

This paper reports the performances of the SPARC laser system. The activities and the major results on the time pulse shaping program have been presented. Two schemes have been applied at the production of the flat top target pulse. The results indicate, for both schemes, that rise time of 1.4 ps can be achieved. Sharper edges require larger bandwidth and it the topic of future investigations. Measurement of the phase noise indicates standard deviation less than 0.5 ps of the UV pulse respect to the RF system.

REFERENCES

[1] M. Ferrario et al., “Experimental results with the SPARC emittance meter”, these Proceedings.
[2] C. Vicario et al, “Commissioning of the Laser System for SPARC Photoinjector”, Proceeding EPAC, p. 3146, Edinburgh, Scotland, 2006.
[3] S. Cialdi, M. Petrarca and C. Vicario, “High power third harmonicflat pulse laser generation” Opt. Lett. 31, (2006), 2885.
[4] S. Cialdi, C. Vicario, M. Petrarca and P. Musumeci, Appl. Opt., Doc. ID 82759, (Posted 05/15/2007, in press).
[5] A. Gallo, M. Bellaveglia, G. Gatti, C. Vicario “Laser and RF Synchronization Measurements at SPARC” these Proceedings.