LASER TEMPORAL PULSE SHAPING EXPERIMENT FOR SPARC PHOTOINJECTOR

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Abstract

Laser for driving high brightness photoinjector have to produce UV square pulse which is predicted to be the optimum profile for emittance compensation in advanced photoinjectors. The longitudinal laser pulse distribution, according to numerical simulations for the SPARC photoinjector, must be square with rise and fall time shorter than 1 ps and flat top variable up to 10 ps FWHM. In this paper we report the results of pulse shaping obtained using an acousto-optic (AO) programmable dispersive filter (DAZZLER). The DAZZLER was used to perform spectral amplitude and phase modulation of the incoming 100 fs Ti:Sapphire pulses. Because of the finite length of the crystal the maximum duration of the shaped pulse is 6 ps. To overcome this limitation we used a configuration in which the laser pulses pass twice through the AO filter. A dispersive glass section was also used to lengthen the pulse with a single pass in the DAZZLER. In this paper we report the experimental setup, hardware description and time and frequency domain measurements.

INTRODUCTION

The SPARC project (Sorgente Pulsata Autoamplificata di Radiazione Coerente) is a 150-MeV advanced photoinjector designed to drive a SASE-FEL in the visible and near UV range[1]. The machine consists of a Ti:Sa laser to illuminate a metal photocathode, an high gradient rf-gun and 3 SLAC s-band accelerating sections. The photoinjector, which is under construction at LNF, is conceived to explore the emittance correction technique and high current production, with proper preservation of the transverse emittance. The aim of the project is to explore the scientific and technological issues for the construction of SASE-FEL based X-ray source.

The photocathode drive lasers for high brightness electron beam applications must show very specific capabilities motivated by two major considerations: the low photo-emission efficiency of robust photocathodes requires high UV energy to extract the needed charge; the emittance compensation process is most successful with uniform temporal and spatial laser energy distribution. In particular beam dynamics simulations confirm that the optimal pulse shape has flat-top profile up to 10 ps, with ripple less than 30% and very sharp edges of the pulse: the rise and fall times must be at least shorter than 1 ps. To assure repeatable SASE-FEL performance, additional demands are low energy fluctuations (<5%), small time jitters from pulse-to-pulse (<1 ps) and good pointing stability. Finally, the laser pulses have to be synchronized with the accelerator master oscillator, in order to extract electrons at a precise phase of the RF field. To satisfy all these requirements it is necessary a pulse shaper device and a large bandwidth laser system; so the Ti:Sa technology was adopted. In Fig. 1 is reported the laser layout for SPARC.

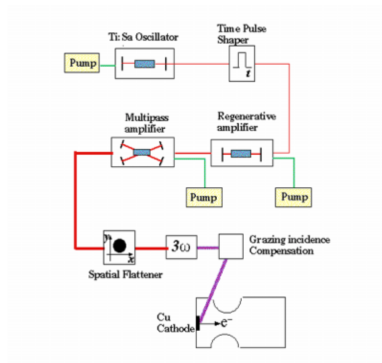

Figure 1: Conceptual layout of SPARC laser system.

The 100 fs pulses delivered by Ti:Sa laser naturally display a sech^2 temporal profile. The device that convert this pulse shape in a flat top one works as a spectral filter. The pulse shaper has high insertion losses and low damage thresholds: therefore the filtering has to be applied before amplifying the laser pulse. Beside, the spectral manipulation has to retain almost all the spectrum of the incoming pulse because otherwise it would induce problems for the amplification process [2].

To produce the desired pulse shape it was proposed a liquid crystal matrix placed between two gratings [3]. The liquid crystal mask can operate as spectral amplitude filter or phase shifter.

Instead we tested a new technique based on a programmable AO dispersive filter produced by FASTLITE (named DAZZLER). This device is able to perform simultaneously amplitude and phase modulation.

Because of the filter behavior of the DAZZLER the output signal in the spectral domain is given by [4]:

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$$S_2(\omega_2) = S_1(\omega_1) \cdot S_{ac}(\omega_{ac}) \quad (1)$$

where S_2, S_1 and S_{ac} are respectively the complex output optical signal, the input signal and the acoustic transfer function.

In details inside the AO filter, a chirped acoustic wave and the optic pulse linear polarized along the ordinary axis interact in a TeO_2 crystal. The AO interaction occurs for different optical wavelengths, at different depths, where the AO phase matching condition is satisfied [5]. The interaction induces a rotation of the polarization toward the extraordinary axis. The refraction index along the extraordinary axis is different from that along the ordinary one and thus a frequency dependent phase delay is obtained. In practice the filter shifts in time the pulse frequencies thus stretching the pulse temporally. The intensity of the acoustic signal governs the amplitude modulation of the optical wavelengths. A radio frequency generator (with frequencies between 40 and 55 MHz) drives a piezo-transducer to produce the acoustic wave in the crystal.

EXPERIMENT OVERVIEW

We tested the DAZZLER at the ULTRAS laboratory of the Politecnico in Milan.

The source used for the experiment was an amplified Ti:Sapphire laser similar to the one expected for SPARC. The laser delivered 20 fs FHWM, 1 mJ pulses at 1 kHz repetition rate with the central wavelength at 800 nm, in horizontal linear polarization. A small fraction of the laser beam (20 μJ) was sent to the experimental setup; here the beam was divided in two arms by a 50% beam splitter.

In the first arm the beam was sent through a 10-nm band pass spectral filter, to obtain 100 fs FWHM pulses (as we expect for the SPARC laser), and then through the DAZZLER crystal. The second pulse (gate pulse) was sent to a delay line controlled by a 100 nm linear resolution stepper motor. For the measurement the shaped pulse and the gate signal overlapped in a non linear BBO crystal. The emerging double frequency pulse was proportional to the cross-correlation of the two pulses, and was measured by a photodiode. The measurement was based on the lock-in technique.

The cross-correlation corresponded in our case to the temporal intensity measurement of the shaped pulses, because the gate pulse was much shorter than the DAZZLER pulse. The resolution was about the duration of the gate optical signal (20 fs).

We developed the numerical code, in Labview environment, to simulate the optimal phase and amplitude modulation for the DAZZLER. The calculation allowed the control of the shaping in real time according to Eq. 1. The program simulates the behavior of the DAZZLER: it allows the modification of the amplitude and the spectral phase of the measured input spectrum, and then, through the FFT, calculate the output temporal profile. With the amplitude modulation we corrected also the non flat response of the DAZZLER due to the frequency-dependent diffraction efficiency. A general comment is that we cannot impose the spectral modulation as sinc function which would give under Fourier Transform a perfect square profile in time. This is because the output pulse would have a too narrow spectral bandwidth, not compatible with Ti:Sa amplifier operation[2].

Because of the finite length of the crystal (2.5 cm) the maximum theoretical duration of the shaped pulse is 6 ps. To overcome this limitation we used a configuration in which the laser pulses pass twice through the AO filter. In this case we observed high energy losses (≈80%). For this reasons we tested also a configuration with a single pass through the DAZZLER crystal and through 30 cm of dispersive glass (SF57). The glass introduced an extra second order phase modulation. The total dispersion of the glass sections was 0.2 ps^2. In this way the losses were reduced to 50%. The single passage simplified also the alignment of the AO crystal.

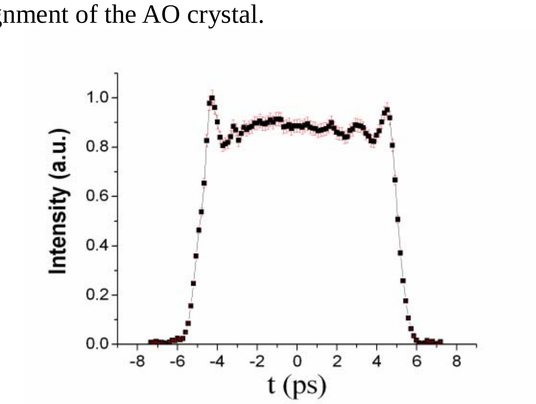

Figure 2: Cross-correlation of the output shaped pulse in double-pass configuration.

In Fig. 2 is reported the cross-correlation signal obtained with double passage configuration, with the estimated error bars. The measured pulse shows a very sharp rise and fall time, definitely less than 1 ps, and the pulse duration is about 10 ps FWHM. The ripple on the top of the pulse is very smoothed. The overshoots remains below 15% of the average value of the pulse intensity. The pulse's characteristics obtained are in good agreement with the SPARC requests for the pulse [6].

In Fig. 3 it is shown the input spectral intensity, the phase and amplitude modulation used to obtain the flat top pulse reported in Fig. 2.

The phase modulation is given by symmetric polynomial expansion up to 8^{th} order centered at 780 nm. The amplitude modulation (absolute value of the transfer function) is given by Eq. 1 assuming a Super-Gaussian output amplitude spectrum:

$$|S_2| = Exp\left[-\left(\frac{|\nu-\nu_0|}{\Delta\nu}\right)^n\right] \quad (2)$$

with the exponent n=9.35, bandwidth $\Delta\nu$=4.14 THz and ν_0 is the central frequency. It is important to stress the fact that we did not impose the DAZZLER a phase curve which gives the same group delay (defined as the derivative of the phase respect to the frequency) for two different frequencies. This in fact could have very deleterious consequences including unstable beat phenomena.

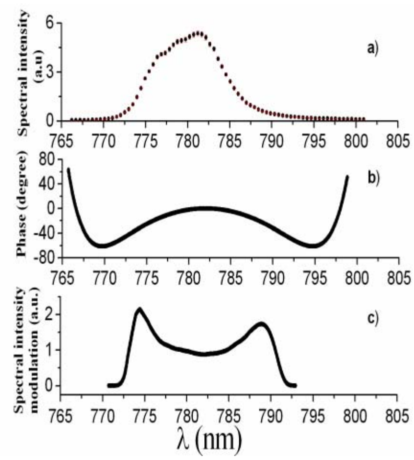

Figure 3: (a) input spectrum; (b) phase modulation; (c) amplitude modulation.

In Fig. 4 is reported the cross-correlation signal with the estimated error bars, obtained with single passage through the AO crystal and the dispersive glass. In this case the rise and fall time is more smooth than the double passage results.

The reason is that in this configuration the DAZZLER dynamics is reduced and the glass introduce only second order phase shift without high orders which are responsible for the rise and fall time duration. Thus we have a lower ripples as the Gibbs phenomenon asserts. However the result still satisfies the SPARC requirements. The duration of the shaped pulse is about 6.5 ps; if a longer temporal pulse duration is requested, it is necessary the insertion of additional dispersive glass.

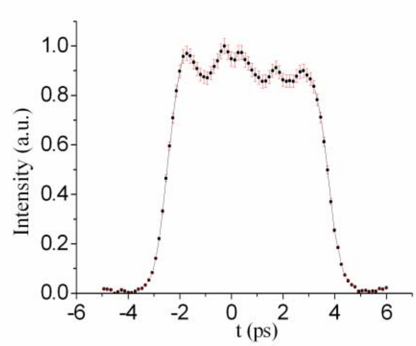

Figure 4: Cross-correlation of the shaped pulse in single-pass configuration.

The best results were obtained with a feedback from cross-correlation measurements and by successive optimizations of the filter's parameters. The cycle went on until we found the best result achievable. For further improvements we think it will be helpful to develop a genetic algorithm with an automatic feedback loop.

The results were reproducible with not appreciable differences, over a time scale compatible with the laser source stability. We observed also a very low influence by beam pointing instability of few mrad. This value is much larger than the typical Ti:Sa oscillator performances. Finally measurements showed that the DAZZLER filter is insensitive to microseconds jitters between acoustic wave and laser pulses.

In the SPARC laser layout the Dazzler is placed ahead of the laser amplifier, therefore the final temporal profile of the pulse on the cathode is determined by the successive processes that the pulse undergoes. The effects of amplification, UV conversion and propagation through the optical transfer line are to be investigated. However the flexibility of the DAZZLER device could also be used to compensate some of these effects. To integrate the DAZZLER in the whole laser system it is required the development of temporal UV diagnostic tools.

OUTLOOK

The experiment conducted was conceived as a proof of the flat top pulse generation by AO crystal.

The preliminary measurements conducted indicate the DAZZLER as a promising technique to produce the required flat top laser pulses up to 10 ps FWHM in double passage configuration. We believe also that, in the single passage configuration, it is possible to obtain longer pulse up to 10 ps with more external dispersion.

We think that better temporal profile can be achieved with a more careful control of the acoustic modulation; this task can be accomplished by improving the control code via genetic algorithm. More work should be devoted to the integration of the DAZZLER with the whole photo-injector laser system and optical diagnostics.

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