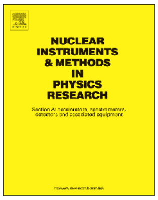
Nuclear Instruments and Methods in Physics Research A ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima



Laser pulse shaping for high gradient accelerators

F. Villa [a,*], M.P. Anania [a], M. Bellaveglia [a], F. Bisesto [a,c], E. Chiadroni [a], A. Cianchi [b], A. Curcio [a], M. Galletti [a], D. Di Giovenale [a], G. Di Pirro [a], M. Ferrario [a], G. Gatti [a], M. Moreno [c], M. Petrarca [c], R. Pompili [a], C. Vaccarezza [a]

[a] INFN-Laboratori Nazionali di Frascati, via E. Fermi 40, 00044 Frascati, Italy
[b] INFN-Roma Tor Vergata and Università di Roma Tor Vergata, Via della Ricerca Scientifica 1, 00133 Rome, Italy
[c] Università La Sapienza di Roma, Via A. Scarpa 14, Rome, Italy

ARTICLE INFO

Keywords:
Laser
Shaping
Accelerator
Multibunch

ABSTRACT

In many high gradient accelerator schemes, i.e. with plasma or dielectric wakefield induced by particles, many electron pulses are required to drive the acceleration of one of them. Those electron bunches, that generally should have very short duration and low emittance, can be generated in photoinjectors driven by a train of laser pulses coming inside the same RF bucket. We present the system used to shape and characterize the laser pulses used in multibunch operations at Sparc_lab. Our system gives us control over the main parameter useful to produce a train of up to five high brightness bunches with tailored intensity and time distribution.

1. Introduction

Recently high brightness linac facilities have studied operation schemes that have more than one electron bunch per RF bucket (LCLS [1], DESY [2], Sparc_lab [3], Fermilab [4] for example). While some facilities, as FLASH and the European XFEL, use a long RF pulse with many bunches in a superconducting linac to increase the total number of bunches [5] available to experiments, we focus on other facilities, as LCLS and Sparc_lab, that have experiments that require a multibunch configuration to operate, having more than one electron bunch in the same RF period.

Resonant Plasma WakeField Acceleration (PWFA) driven by electron bunches uses one or more electron bunches to drive an high gradient acceleration of a smaller witness bunch inside a plasma medium. Other high gradient acceleration experiments, such as wakefield dielectric acceleration [6], also require a specific train configuration of many electron bunches. Multibunch operation is also required in many experiments of two color FEL for pump-probe or stroboscopic experiments [7–9] or in generation of monochromatic THz radiation used in material studies [10,11].

Those configurations require the production of two or more electron bunches with very specific characteristics, as energy, transverse dimensions, time duration and separation, that can be different for each bunch of the train. The generation of electron trains with a pulse separation of few ps or less relies on different schemes, for instance a single long electron bunch is sliced by a mechanical slits system placed in a dispersive area [4,12] or a train of bunches is longitudinally manipulated using velocity bunching [13].

In the latter configuration a train of laser pulses generates a train of electron bunches, it is further manipulated with velocity bunching compression [14] and accelerated inside the linac. A laser system that can shape and control the laser pulses temporal and transversal dimensions and energy for each pulse is required. We present different laser system configurations to achieve the required pulses characteristics and experimental results from Sparc_lab about the generation, characterization and use of those pulses in an high brightness linac.

2. Pulse train generation and characterization

We focus our attention on the techniques to generate a train of pulses that can be used also with UV pulses, as metallic cathodes require wavelengths shorter than visible light to photoemit. As an example, the Sparc_lab RF gun (an S-band, 1.6 cell copper gun) requires a wavelength of about 266 nm. The quantum efficiency of our cathode is in the order of 10^{-5}, thus it requires many tens of μJ of UV energy to generate hundreds of pC. Many techniques can be used in order to generate a train of longitudinal pulses [15]. A simple technique to obtain a ps-train of laser pulses uses the birefringence properties of crystals [16]. Those crystals have two

---

[*] Corresponding author.
E-mail address: fabio.villa@lnf.infn.it (F. Villa).

http://dx.doi.org/10.1016/j.nima.2016.01.010
0168-9002/© 2016 Elsevier B.V. All rights reserved.

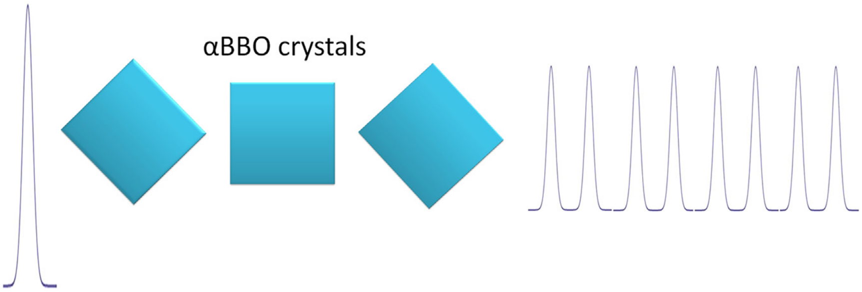


Fig. 1. Laser pulse train generation with birefringent crystals.

different diffraction indexes depending on the orientation of the laser polarization with respect to the crystal optical axis. Choosing the laser polarization it is possible to set how much energy will propagate along the fast and slow axis of the crystal (Fig. 1).

The crystal induces a longitudinal separation (Δt) between the pulses of Δt=(ne-no)L/c, where no (ne) is the ordinary (extraordinary) diffraction index and L is the crystal thickness. The two pulses have orthogonal polarization. It is possible to have more crystals of different length in series in order to obtain more pulses. Usually αBBO crystals are used, because they have a good transmission and strong birefringence in the UV spectral region [6]. This scheme is very simple and efficient: it does not require a precise alignment of the crystal other than rotation; the transverse position of the pulses is not shifted; it requires only n optical elements (the crystals) to obtain $2n$ pulses; the losses of the system are minimal (mainly due to surface reflection and crystal absorption). Major drawbacks of this configuration are: the distances between the pulses are fixed; the number of pulses are exactly doubled for each crystal; the distance between each pulse is not set independently for more than two pulses.

Another technique is based on splitting the pulses and make them propagate on different paths before recombining in a interferometric like configuration (Fig. 2) [17].

In this configuration a linearly polarized laser pulse is divided by a polarizing beam splitter. One pulse is retarded with a geometrical delay line and recombined with the other by a polarizing beam splitter. The first half wave plate can rotate the polarization in order to define how much energy send in each arm. They can also accommodate other optics in order to have also a different transversal or longitudinal shape for each pulse. This scheme is simple enough in case of two pulse generation and have a great degree of customization for transverse, longitudinal and energy characteristics of each pulse, but it requires a precise alignment in the transverse direction because the following transport optics could change the relative transverse position of the two pulses. This scheme is not easily scaled to more than two pulses. One option is to split the initial pulse many times with half wave plates and polarizing beam splitters to obtain the desired number of pulses, having half of them with a polarization and the other half (minus one for odd total pulses) with the orthogonal one. When the pulses are recombined there is a loss of half the energy for each recombination after the first one: when more than two pulses are sent to a polarizing beam splitter only two orthogonal polarization direction are available, resulting in the interleaving of only half the pulses or, with a 45° rotation of the polarization, of only half of the energy of each pulse. Other options, for instance reported in [18,19], have less losses and are more compact than this scheme, but are limited to configuration of power of 2 pulses with less-than-optimal number of separation degree of freedom, like the birefringent crystal scheme described before.

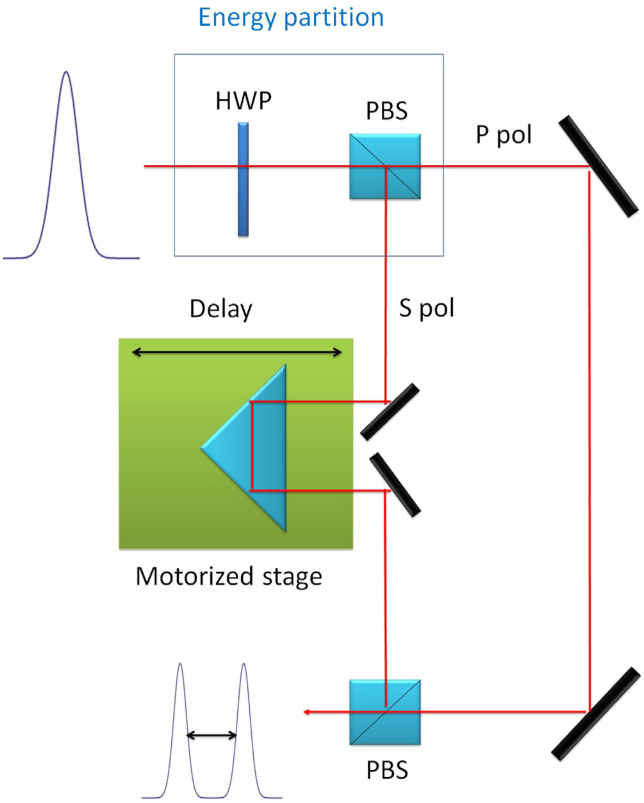


Fig. 2. Scheme of train of 2 pulses generated by a interferometric-like configuration. HWP: half wave plate, PBS: polarizing beam splitter.

Other techniques involving optical dispersion can also be implemented, such as the interference of two stretched pulses in order to have a train of a large number of pulses [11] or phase [15] and amplitude [20,21] manipulation in the Fourier plane of a 4f system.

Longitudinal characteristics should be precisely measured to fully characterize the laser train. Crosscorrelation with a IR laser can solve the problem of having an high resolution in long time window. These measurements are done measuring the energy of the pulse generated by the frequency difference process inside a nonlinear crystal between the UV train pulse to be characterized and the IR single peaked probe (Fig. 3) [22].

The crosscorrelation profile is obtained by a multishot measurement changing the delay of the IR pulse. The profile is strongly affected by amplitude jitter, that can be reduced by averaging on many shots per IR delay position. The resolution of the system is limited by the shorter step that the delay line can set (5 μm) and by the IR pulse length (a fwhm between 0.7 and 1.3 ps. The IR

Please cite this article as: F. Villa, et al., Nuclear Instruments & Methods in Physics Research A (2016), http://dx.doi.org/10.1016/j.nima.2016.01.010