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A simple gating technique for high-average-current photo-injectors

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ABSTRACT

This paper describes a simple method that substantially improves the production of gated electron bunch trains by totally suppressing undesired background photoemission between the trains. A device has been designed and tested with a drive laser for proof-of-principle demonstration. The predicted functionality and performance are verified on an Energy-Recovery-Linac (ERL) electron accelerator. The method can find applications whenever the laser pulse repetition rate and length need to be tailored.

1. Introduction

Accelerator-based light sources comprising a photoemission electron source [1–3] put stringent demands on the photo-cathode driver laser parameters, such as pulse length, wavelength, power, repetition rate, beam quality, intensity and phase stability [4–7]. Such accelerator systems consist of many complicated components and demand a very high degree of care in implementation of a well-developed procedure for initial machine tuning and parameter set up. One of the most basic and important requirements on the drive laser is to provide various macro-pulse lengths and repetition rates because the linac is operated in continuous-wave (CW) mode and the laser is the only practical way to control the electron bunch format. During high current production runs, the laser is run CW (at a sub-harmonic frequency of the linac) but during tune-up mode one needs to gate the laser to form macro-pulses consisting of micro-pulses. The accelerator has to be set up at low current (which means low pulse repetition rate at a certain pulse lengths) before operating in a high current mode. Since the drive laser micro-pulses are MHz to GHz quasi-CW pulse trains generated by picosecond (ps) mode-locked oscillators and amplifiers, fast electro-optic (EO) devices are usually used to chop out a macro-pulse with certain time duration and repetition rate. As shown in Fig. 1(a), the macro-pulse length is determined solely by the on and off time of a Pockels cell which is driven by a high voltage electrical pulse. Leakage through the Pockels cell (referred to here as "ghost pulse") always exists due to the limited contrast of Pockels cells. The presence of the ghost pulses imposes a major obstacle to the operation of the accelerator, as it will interfere with the electron beam diagnostics and may cause excessive radiation along the beam line. They therefore need to be eliminated or minimized to below a certain level. The alternative option of using multiple Pockels cells can increase the pulse contrast only at the expense of substantial increase of cost, alignment difficulty and laser power loss.

The best way to eliminate unwanted laser pulse is to block them completely. In case of the time duration (sub-μs to ms domain) required by the accelerator, it is possible to use a fast mechanical shutter for such a purpose. Fig. 1 depicts how a macro-pulse is generated by the combination of both a Pockels cell and a mechanical shutter. There are two distinctively different groups of pulses in Fig. 1(a) in terms of the pulse amplitude. The low amplitude (ghost) pulses are the leakage through the EO switches used for reducing micro-pulse frequency. The high amplitude pulses are not modulated by EO devices and remain the same as those at the original fundamental laser frequency. This system has proven to become an indispensable part of the drive lasers for high-average-current accelerators such as ERL systems. The Pockels cell provides a flat time window with fast leading and falling edges that have to be shorter than the interval between two micro-pulses (usually a few ns). A wider time window from the mechanical shutter eliminates the ghost pulses outside the Pockels cell window, thus significantly improving the overall pulse contrast by eliminating most of the ghost pulse leakage (see illustration in Fig. 1). Here, we define the integrated pulse contrast ratio (IPCR) as the ratio of the overall content of signal pulses over the accumulated ghost pulses (or the sum of all the signal pulses over that of the total ghost pulses). Unlike in a low repetition laser system where the contrast ratio usually means the amplitude ratio of a signal pulse over the adjacent

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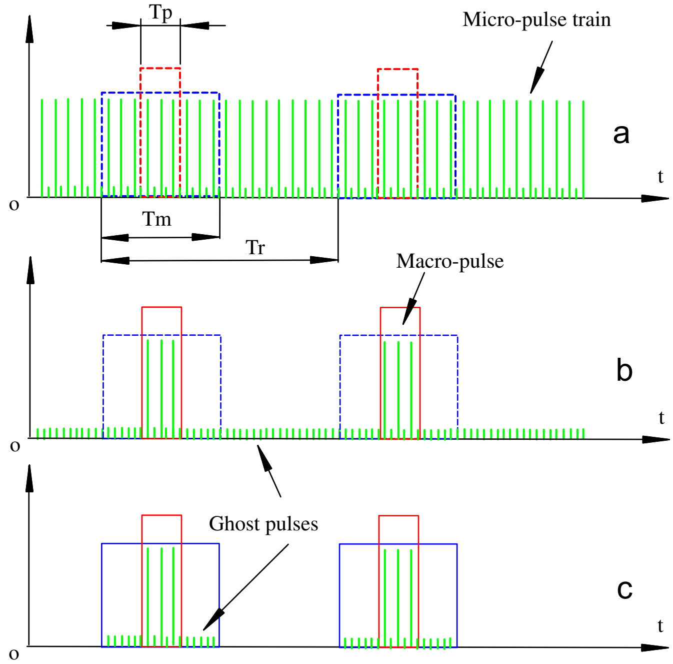

Fig. 1. Schematic of macro-pulses generated from a drive laser pulse train. (a) CW micro-pulse train (green comb), Pockels cell open time Tp (red dashed), mechanic shutter open time Tm (blue dashed). Macro-pulse period is Tr. (b) Macro-pulse generated by Pockels cell (green pulses in red area). (c) Macro-pulses generated by both Pockels cell and mechanical shutter (denoted by blue window). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

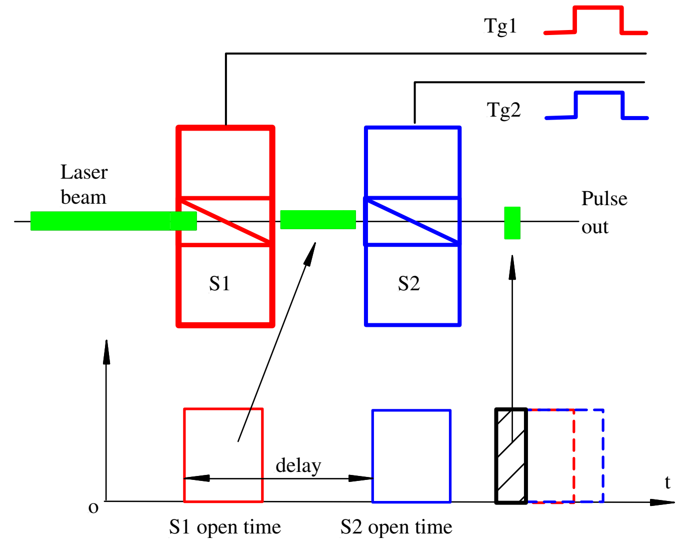

Fig. 2. Diagram illustrating the idea of a dual-shutter system. A proper delay between two shutters generates a differential time window that enables variable laser pulse duration at the output and allows shortening of the opening window. S1 and S2, shutters. Tg1 and Tg2, trigger signals.

satellite pulse, IPCR is more important for high repetition electron beam accelerators. As an example, the Jefferson Lab FEL drive laser repetition rate is 74.85 MHz, the standard accelerator tune-up mode operates with a 4.68 MHz (16th sub-harmonic of 74.85 MHz) micro-pulse repetition rate, 2 Hz macro-pulse repetition rate and a 250 μs pulse length. Assuming the Pockels cell contrast ratio for both macro-pulse and micro-pulse is 5×10^4, the IPCR will be less than 2, which is unacceptable. With a mechanical shutter in and a typical time window of 2.5 ms, the IPCR will be over 200 times higher. This explains the important role that such a shutter plays.

Since it is extremely difficult to further shorten the mechanical shutter's minimum time window (typically a few ms long), the ghost pulses inside its exposure window cannot be eliminated. Moreover, the macro-pulse length generated by the Pockels cell is variable and can be as short as sub-μs where the ghost pulses start to take dominant portion of the contrast due to the relatively smaller number of main signal pulses. Therefore a mechanical shutter with a variable time window that follows the macro-pulse duration is needed to further improve the overall contrast. The idea to be presented here is called dual-shutter scheme as shown in Fig. 2 where two shutters are placed in series to produce a differential time window. Since each shutter will open and close as controlled by its trigger, a proper delay between the triggers will make the variable differential window possible. The 1st shutter will let out a portion of the input laser within its open time window. The 2nd shutter will not open until triggered at a designated time, therefore yielding a much narrower time window. The leading and the falling edges are determined by the 2nd and the 1st shutter, respectively. If the input is the macro-pulse from a Pockels cell, its falling edge should be kept close to that of the 1st shutter, and the ghost pulses preceding the signal pulse will be blocked by the delayed leading edge of the 2nd shutter. The minimum window is only limited by the actual rise and fall time of the shutters.

2. Experiment and result

There are different types of commercial mechanical shutters specifically designed for laser application. Among those that have been tested with lasers, the electro-mechanical shutter [8] (Model LST200, from nmLaser Products, Inc.) shows relatively faster switching response and good stability. There is no observable jitter from the gated laser pulse on the oscilloscope. For many applications, the shutter is also required to handle certain laser power. The basic principle of this kind of shutter is simple and available at the vendor's website (www.nmlaser.com). Fig. 3(a) shows the working mechanism and pictures of the shutter we used for the work described in this paper. nmLaser uses a magnetic cantilever beam that has good thermal conductivity and excellent spring properties. When no trigger signal is present, the light path is completely blocked and laser energy is safely dumped into the shutter absorbing body. Once triggered by the electrical pulses from the controller, the cantilever is magnetically pulled to the open position and the laser beam is allowed to pass through. Faster switching speed is achieved by using a stiffer flexing beam and a powerful closely coupled cylindrical toroid electromagnet with pole curvature designed to match the catenary curve of the cantilever flexure beam. The optically coated cantilever surface also helps to minimize laser power deposited into the switch itself. If excessive heat is generated in the switch, a chiller can be used to keep the shutter at nominal temperature to prevent failure. The gating mechanism by the simple mechanical movement of the cantilever flexure provides high reliability. This kind of shutter technology also eliminates the problems associated with friction pivots, hinges and bearings with lubrication outgas, which can be detrimental to high power laser optics near the shutter.

The experimental setup is illustrated in Fig. 3(b). Either of the two shutters can be forced open when only a single shutter is needed. The TTL triggers to the shutter controllers come from a multi-channel synchronization signal pulse generator with variable time delay. The laser pulses are generated from a diode-pumped solid-state system. Each micro-pulse is about 20 ps long. The combination of a Pockels cell and a polarizer produce a macro-pulse whose pulse width is determined by the high voltage electrical driving pulse applied to the Pockels cell. Two identical shutters are well aligned to allow clean beam throughput. The laser pulse signal received by a fast photo-diode