GENERATION AND DIAGNOSTICS OF NANOSECOND-INTERVAL LASER PULSE TRAINS WITH FEMTOSECOND-LEVEL TIMING CONTROL FOR THE KOREA-4GSR PHOTOCATHODE RF GUN

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Abstract

The Korea-4GSR (4th Generation Storage Ring) requires a highly stable and precisely synchronized laser pulse train to drive its photocathode RF gun in multi-bunch mode. To meet this requirement, we developed a laser system capable of generating nanosecond-interval pulse trains with femtosecond-level timing control. The pulse train is formed using a beam-split/delay-and-combine method, producing a 64-pulse sequence with 2 ns separation, synchronized to a 500 MHz RF reference. To further enhance synchronization accuracy and diagnose timing jitter at the femtosecond scale, a 500 MHz femtosecond oscillator is being developed and integrated into the system. This fs-oscillator enables precise timing diagnostics, long-term drift monitoring, and improved stability for multi-bunch operation. The combined system is designed to provide low-emittance, low-energy-spread electron bunches required for Korea-4GSR's high-brightness injector and ensures reliable operation in both single-shot and multi-bunch modes.

Introduction

The Korea-4GSR injector is designed to generate high-brightness electron beams for stable multi-bunch operation. The injector consists of a photocathode RF gun and a linear accelerator system, where precise control of the initial beam conditions is critical for achieving low emittance and low energy spread. As shown in Fig. 1, the overall injector system includes the RF gun, accelerating structures, and beam transport line. In such a system, the performance of the electron beam is strongly influenced by the laser-driven photocathode, requiring a highly stable and precisely synchronized laser pulse train.

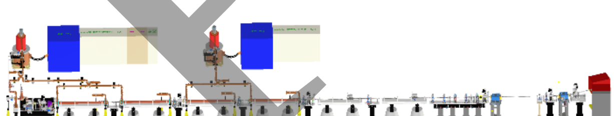

Figure 1: Korea-4GSR injector system including the photocathode RF gun, accelerating structure, and beamline components.

Laser System

A laser system has been developed to generate a multi-pulse train suitable for driving the Korea-4GSR photocathode RF gun in multi-bunch mode. The system is designed to produce a sequence of 64 laser pulses with a temporal separation of 2 ns, corresponding to a repetition rate of 500 MHz, synchronized to the RF reference signal. As shown in Fig. 2, the pulse train is generated using a beam splitting, delay, and recombination scheme, in which a single input pulse is divided into multiple paths with carefully controlled optical delays. These delayed pulses are then recombined to form a temporally structured pulse train. The entire system is designed to maintain high temporal precision and stability while ensuring uniform beam characteristics across all pulses. This configuration enables flexible generation of multi-bunch laser patterns while maintaining compatibility with the RF synchronization requirements.

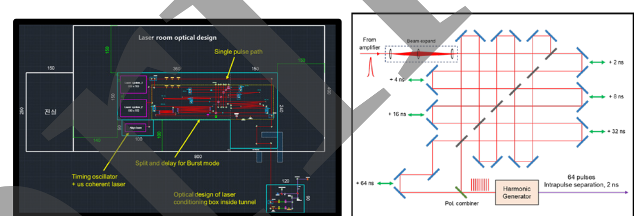

Figure 2: 4GSR laser room optical design and Split and delay for burst mode schematic.

Timing Synchronization Diagnostic Setup

This diagnostic system (Fig.3) is designed to synchronize the pulse spacing with a reference frequency (~500 MHz). The multi-pulse laser train is cross-correlated with quasi-CW pulses from a timing reference laser oscillator synchronized to the RF reference. By scanning the relative time delay on the reference oscillator side, the cross-correlation signals of individual pulses within the 64-pulse train can be resolved. This enables direct measurement of the relative timing offsets among the pulses. With sufficient signal averaging, the pulse train can be temporally aligned with an accuracy better than 200 fs.

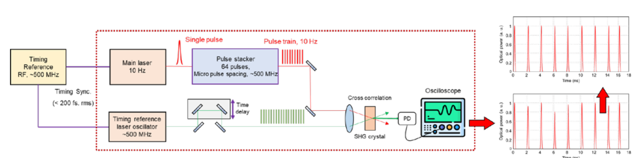

Figure 3: Timing synchronization diagnostic setup, The pulse train with a repetition rate of 500 MHz, corresponding to a pulse spacing of 2 ns.

500 MHz Femtosecond Laser Oscillator

As shown in Fig. 4, the pump source is a single-mode, fiber-coupled, linearly polarized laser diode delivering 1000 mW at 980 nm. The laser cavity has a Z-shaped configuration with a length of 30 cm to achieve a repetition rate of 500 MHz, and the pulse duration is expected to be less than 200 fs. Due to the relatively low power of the pump, no degradation of the laser performance was observed without active cooling during the experiment [1].

In our experiment, with a cavity length 30 cm, a repetition rate of 500 MHz, and a pump power of 880 mW, continuous-wave (CW) lasing was obtained with an output power of 206 mW.

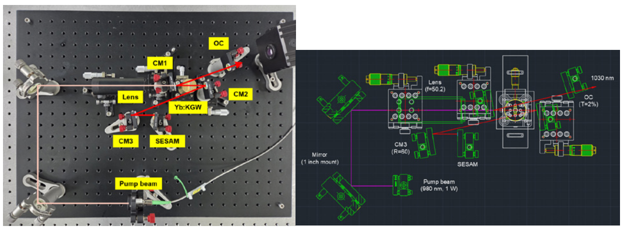

Figure 4: 2D AutoCAD drawing and actual experimental setup (Pump beam: 980 nm, 880 mW CW; Lens: f = 50.2 mm; Yb:KGW: Yb 5% doping, 3 mm; CM1: R = 50 mm, 1030 nm HR, 980 nm AR; CM2: R=50 mm, 1030 nm HR, GDD = -550fs^2; CM3: R = 60 mm, 1030 nm HR, GDD = -500 fs^2; OC: T = 2%).

CONCLUSION

Our future goal is to create a 64-pulse train using the split and delay method with flexibility (e. g. number of bunches, time intervals). We aim to precisely control the pulse energies and intervals between pulses using our developed 500 MHz femtosecond laser oscillator with feedback. Ultimately, we intend to utilize this refined pulse train for the various multi-bunch mode operation of Korea-4GSR's photo-cathode RF gun, and we will align the laser specifications(Table 1) accordingly.

Table 1: Korea-4GSR Linac Laser System Specifications

Parameter	Single bunch mode	Multi-bunch mode
UV pulse length	6-8 ps FWHM	6-8 ps FWHM
UV pulse energy	> 100 µJ	> 100 µJ (64pulses)
UV pulse energy stability	< 2 %	< 5 %
Timing sync stability	< 200 fs rms	< 200 fs rms
Repetition rate	2 Hz 10 Hz	2 Hz 10 Hz

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