CHART Scientific Report

ns-Pulser

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1. Goals of this project

Currently, many large synchrotron facilities are being upgraded, or plans exist to upgrade them to so-called fourth-generation light sources as for example the Swiss Light Source 2.0 at PSI in Switzerland or the PETRA IV at DESY in Germany. These upgrades target extremely low beam emittances that are associated with smaller accelerators' dynamic aperture. The latter requires improved injection techniques to ensure sufficient injection efficiency. The considered injection schemes from the booster accelerator to the storage ring as shown in Figure 1 require an injection or an extraction of single electron bunches. During such an injection/extraction process, it is important to minimise the disturbance of neighbouring bunches. This means that the deflection time of the kickers must not be more than twice the normal distance between directly consecutive bunches. Figure 1 shows, for example, that an injected bunch fills the "gap" between two bunches with twice the normal distance, so that after the kicker all bunches have the same distance. For the considered SLS 2.0 at PSI this time limit is in the range of approximately only 4 ns [1]. In addition, for some advanced injection modes, as for example an on-axis longitudinal injection, the injected bunch should be positioned between two regular bunches, so that the allowed maximum deflection time is even only half the time described above, i.e. in the considered case 2 ns. Consequently, a high bandwidth of the kicker system is mandatory and very short high-voltage pulses in the kV-range for driving the kicker systems are required. Furthermore, ultra-fast rising and falling edges of the pulses are required to effectively use the limited kick time. The targeted pulse specifications for this project are summarized in Tab. 1. The short voltage pulses are typically generated by ultra-fast solid-state pulse generators. Such ultra-fast pulse generators are also a key element for triggering fast thyristors, which are currently investigated at CERN for replacing thyratrons [2, 3].

Table 1: Pulse specifiations

Peak voltage	10 kV – 15 kV
Peak current	200 A – 300 A
Pulse duration	< 1.5 ns
Rise/fall time	< 400 ps

To meet these requirements, this project focuses on the design of ultra-fast solid-state pulse generators utilizing inductive energy storage and diode opening switches. The project scope encompasses both system-level design, including pumping circuits for the opening switches, and also device-level engineering of the semiconductor switches.

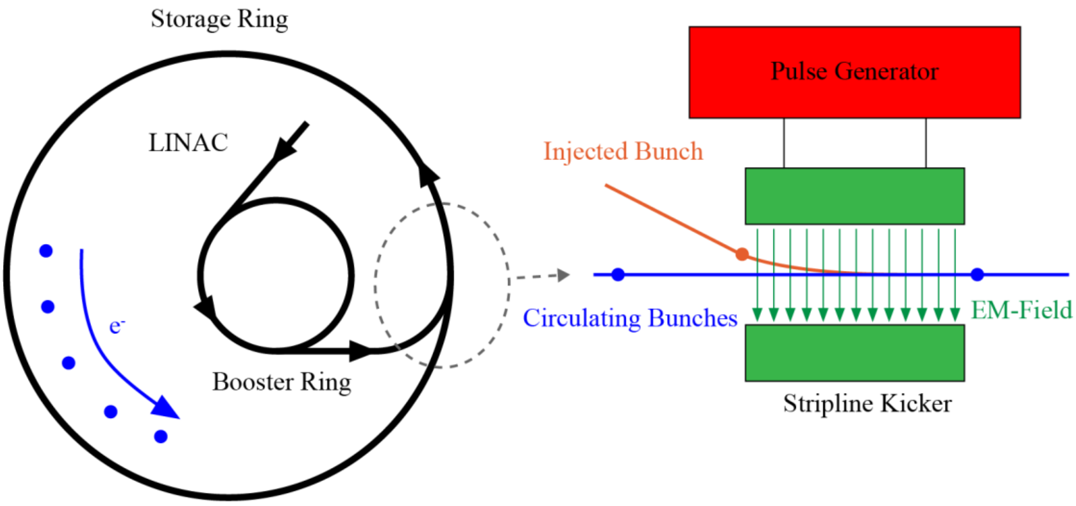

Figure 1: Schematic depiction of a synchrotron light source and the injection of electron bunches into the storage ring.

2. Current State

2.1 System Level

First, a comprehensive literature analysis was conducted to obtain an overview of pumping circuits used in ns-pulser systems. The objective of this review was to identify circuit topologies capable of generating high-voltage pulses with nanosecond rise times while maintaining controllability and system efficiency. An example of such a circuit topology is shown in Fig. 2. In a second step, the topologies were evaluated according to multiple criteria, including amplitude tuning capability, the required number of switching and passive elements, available degrees of freedom for circuit optimization, component stress, and overall implementation complexity. The comparison allowed the identification of promising configurations that provide sufficient flexibility for pulse shaping while keeping the hardware requirements manageable.

Currently, pumping circuit candidates are being assessed with respect to parasitic elements. Due to the ultra-fast pulse edges, the impact of parasitics like stray inductances between the opening switch and the load or the parasitic capacitance of the opening switch stack have a significant impact on the performance of the system. Slower pulses or undesirable oscillations can e.g. be caused by the parasitic elements in practical designs. Therefore, considering and modelling these elements is essential for the design of the pulse generator

The next steps for the system-level design part of the project consist of the extension of the already ongoing analysis of parasitic elements. Furthermore, the design and implementation of pumping circuit prototypes is planned. These prototypes are intended to deepen the understanding of the circuits and will serve as a platform to assess the behaviour of opening switches.

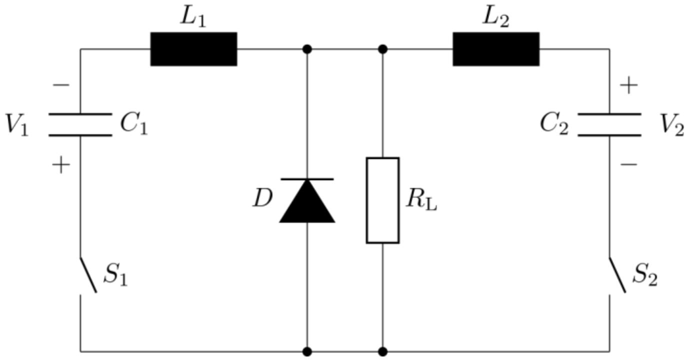

Figure 2: Circuit diagram of an example pumping circuit adapted from [4].

2.2 Device Level

In addition to the circuit topology analysis, the physical behaviour of the opening switch (marked as D in Fig. 2), an essential component for achieving extremely fast pulse transitions, was studied through first simplified simulations. The simulations focused on understanding the dynamic processes involved during the switching event, particularly the mechanisms responsible for the rapid interruption of current that enables nanosecond-scale pulse generation. In order to calibrate the simulations and further understand the switching, characterization of commercially available fast diodes was performed.

Furthermore, preliminary analysis on interaction between the opening switch and the surrounding circuit parameters was performed. Parameters such as capacitance and load conditions were considered in this first rough analysis.

3. Literature

[1] M. Paraliev et al., “Development of fast and super-fast kicker system for SLS 2.0 injection,” in Proceedings of the 12th International Particle Accelerator Conference, (Campinas, SP, Brazil, May 24–28, 2021), pp. 2889–2892. doi: 10.18429/JACoW-IPAC2021-WEPAB122

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[4] R. J. Focia, E. Schamiloglu, and C. B. Fleddermann, “Simple techniques for the generation of high peak power pulses with nanosecond and subnanosecond rise times,” Review of Scientific Instruments, vol. 67, no. 7, pp. 2626–2629, Jul. 1996, issn: 1089-7623. doi: 10.1063/1.1147191

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[6] A. F. Kardo-Syosev, “New power semiconductor devices for generation of nano-and subnanosecond pulses,” in Ultra-Wideband Radar Technology, J. D. Taylor, Ed. CRC Press, 2001, ch. 9, pp. 205–290, isbn: 0-8493-4267-8.

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