

# PULSED POWER SUPPLY BASED ON AN OPTICALLY TRIGGERED THYRISTOR FOR THE NONLINEAR KICKER MAGNET OF HALF\*

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## Abstract

A pulsed power supply based on a high-voltage optically triggered thyristor has been developed for the nonlinear kicker (NLK) magnet of the off-axis injection system at the Hefei Advanced Light Facility. The NLK requires a short high-current pulse with a waveform close to a half-sinusoidal waveform, fast current rise, and low distortion. An LC resonant topology was adopted and an optically triggered thyristor was used as the main switch. A saturable inductor was introduced to suppress high-frequency oscillations during the current rise. Experimental results show that the developed system can generate a pulse width below 3.2  $\mu\text{s}$  with a peak current of 5 kA and a current rise rate of about 6.25 kA/ $\mu\text{s}$ . The output waveform is closer to the required half-sinusoidal profile than that obtained with a conventional thyristor-based design, demonstrating the suitability of the proposed power supply for kicker magnet applications in advanced light-source facilities.

## INTRODUCTION

The Hefei Advanced Light Facility (HALF) adopts an off-axis injection scheme in which a nonlinear kicker (NLK) magnet is used to minimize beam disturbance during injection [1]. The NLK magnet requires a pulsed power supply capable of generating a high-current short pulse with a half-sinusoidal waveform, fast current rise, and low timing jitter [2,3]. These characteristics directly influence the orbit closure and injection efficiency [4]. In pulsed magnet systems, the switching device plays a key role in determining the output waveform. Conventional switches such as thyristors or IGBTs can be used, but high-voltage short-pulse operation often requires complex circuit structures and may be limited by switching speed or device ratings [5]. In this work, a pulsed power supply based on a high-voltage optically triggered thyristor is proposed. Combined with an LC resonant topology and waveform optimization using a saturable inductor, the system can generate a high-current pulse with a waveform close to the desired half-sinusoidal waveform [6].

## POWER SUPPLY DESIGN

The pulsed power supply is based on a series LC resonant topology. As shown in Fig. 1, the system consists of a charging circuit, a pulse-forming circuit, an energy-dissipation circuit, and a buffer protection circuit. The energy-dissipation circuit is implemented by a series resistor-diode branch connected in parallel with the energy-storage capacitor to suppress oscillation, while the buffer protection

circuit employs an RCD snubber. The NLK magnet and the energy-storage capacitor form the resonant loop. After the thyristor is triggered, a sinusoidal current is generated and naturally interrupted after half a cycle by reverse blocking, resulting in a half-sinusoidal output current.

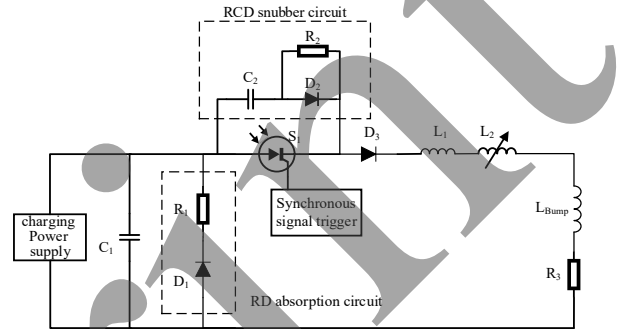


Figure 1: Block diagram of the optically triggered thyristor pulsed power supply.

In the practical design, the equivalent resistance of the NLK magnet is no greater than 10 m $\Omega$ ; therefore, the circuit can be approximated as a lossless LC resonant circuit for parameter estimation. The excitation pulse current can be expressed as shown in Eq. (1).

$$i(t) = \frac{U_0}{\omega_0 L} \sin \omega_0 t \quad (1)$$

and the peak current is given by:

$$I_0 = U_0 \sqrt{C/L} \quad (2)$$

The half-sinusoidal pulse width is given by:

$$T_d = \pi \sqrt{LC} \quad (3)$$

and the current rise time can be approximately expressed as:

$$T_r = T_d / 2 \quad (4)$$

According to the HALF injection scheme, the peak excitation current of the NLK magnet is derived to be 4654 A. Based on Eqs. (1)–(4), the following circuit parameters were selected to satisfy the design requirements: an initial charging voltage of 20 kV, an energy-storage capacitor  $C_1$  of 0.30  $\mu\text{F}$ , and a single-turn NLK magnet with an inductance of 2.2  $\mu\text{H}$ . Considering that the total parasitic inductance is less than 1.3  $\mu\text{H}$ , the total circuit inductance is estimated to be less than 3.5  $\mu\text{H}$ . The calculated pulse width is 3.2  $\mu\text{s}$ , and the corresponding current rise time is approximately 1.6  $\mu\text{s}$ , yielding a minimum required current rise rate of 3.125 kA/ $\mu\text{s}$ .

To provide sufficient design margin, a TECHSEM PCSS-D50 optically triggered thyristor was selected as the main switch. Figure 2 shows the TECHSEM PCSS-D50

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optically triggered thyristor used in the prototype. The device has a working voltage of 8.5 kV, a maximum pulse current of 18 kA, and a maximum di/dt of 50 kA/ $\mu$ s, which fully satisfies the switching requirements derived from the circuit design. Table 1 summarizes the main specifications of the excitation pulsed power supply and provides the design targets for prototype development.

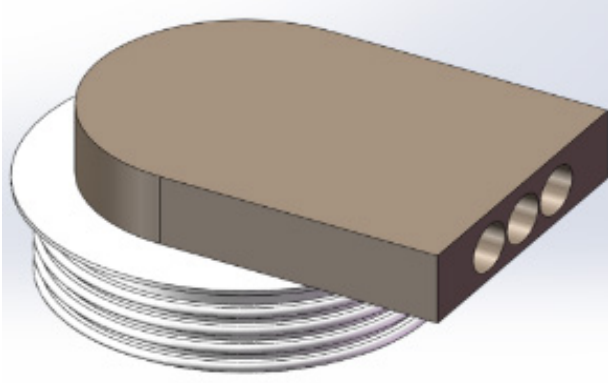


Figure 2: TECHSEM PCSS-D50 optically triggered thyristor used in the prototype.

Table 1: Main Parameters of the Pulsed Power Supply for the Injection-System Kicker Magnet

Pulse width [ $\mu$ s] / waveform	Peak current [A]	Timing jitter [ns]
3.2 $\mu$ s half sine wave	4654	<10
Current rise rate [kA/ $\mu$ s]	Amplitude stability (RMS, 0.5 h)	Waveform consistency error
3.125	0.2 % (0.5h)	<1 %

## EXPERIMENTAL RESULTS

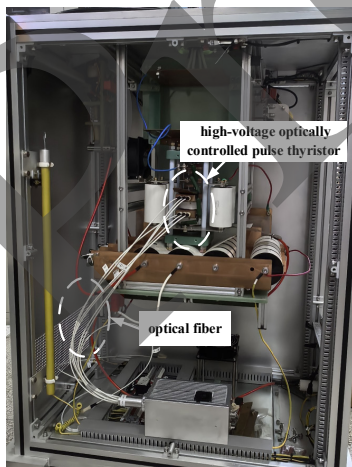
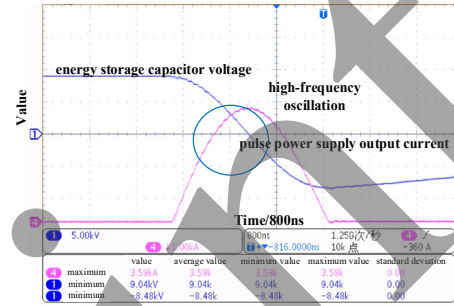


Figure 3: Prototype of pulse power supply.

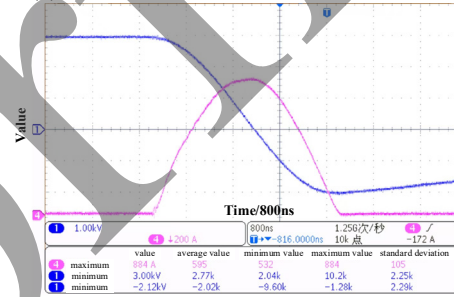
A prototype pulsed power supply was constructed to verify the proposed design. Figure 3 shows the photograph of the constructed prototype pulsed power supply. DC power supply was used as the charging source and operated at 20 kV. The energy storage capacitor bank consisted of

seven 0.1  $\mu$ F capacitors connected in parallel, and the main switching device was the TECHSEM optically triggered thyristor.

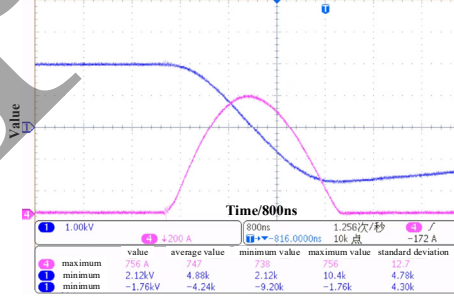
The influence of trigger power on the switching performance was also investigated. A higher trigger drive current resulted in a higher current peak, a faster current rise, and a smoother waveform, whereas insufficient trigger power introduced high-frequency interference into the output waveform. In the subsequent tests, the drive current was set to 150 A to obtain improved switching performance.



(a) Without series saturable inductor.



(b) Single-turn series saturable inductor.



(c) Two-turn series saturable inductor.

Figure 4: Excitation current waveform with different saturable inductor configurations.

During the initial prototype testing, the excitation pulse source operating with the switch exhibited high-frequency ripple on the rising edge of the pulse current. After reducing the parasitic parameters of the circuit, such as shortening the ground lead of the capacitor, some high-frequency oscillations still remained, as shown in Fig. 4(a). Therefore, a saturable inductor was inserted in series with the cathode of the fast recovery diode to further suppress the oscillatory current. This modification improved the turn-on characteristics of the optically triggered thyristor, resulting in a shorter current rise time and a pulse width closer to the design target.

As shown in Fig. 4(b) and Fig. 4(c), the rise time with a single-turn coil is significantly shorter than that with a two-turn coil, whereas the output current waveform with a two-turn coil is smoother. Considering these factors comprehensively, a single-turn configuration was selected to reduce the inductance and achieve the required fast current rise rate.

To clearly demonstrate the superior performance of the high-voltage optically triggered thyristor in this application scenario, the output current waveform was also compared with that of a conventional thyristor (MKP10-055) during the test, as shown in Figure 5. The output current obtained with the conventional thyristor exhibits a slower rise rate. In contrast, the optically triggered thyristor used in this work produces a more symmetric waveform that is closer to the ideal half-sinusoidal profile.

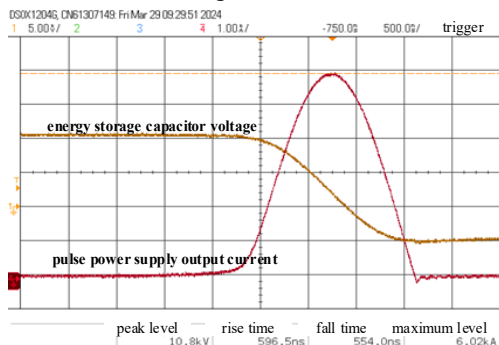


Figure 5: Output current waveform obtained with the conventional thyristor MKP10-055.

The developed pulsed power supply based on the high-voltage optically triggered thyristor was tested with the NLK magnet as the load. After stable operation for 0.5 h, the pulse current was characterized. The measured results show a pulse width of less than 3.2  $\mu\text{s}$ , a peak current of 5000 A, and a current rise rate of about 3.125 kA/ $\mu\text{s}$ . The ripple is 0.15%, the timing jitter is below 10 ns, and the amplitude stability of the excitation current, expressed as the RMS variation over 0.5 h, is better than 0.2%. These results satisfy the design requirements. Compared with the conventional thyristor MKP10-055, the optically triggered thyristor provides a faster current rise, a waveform closer to the required half-sinusoidal profile, lower timing jitter, and improved electromagnetic immunity.

## CONCLUSION

A pulsed power supply based on an optically triggered thyristor has been developed for the NLK magnet of the HALF off-axis injection system. By combining a series LC resonant topology with saturable-inductor-based waveform optimization, the prototype achieved a pulse width below 3.2  $\mu\text{s}$ , a peak current of 5 kA, and a current rise rate of about 6.25 kA/ $\mu\text{s}$ . The measured waveform is close to the required half-sinusoidal profile, with low ripple, low timing jitter, and good amplitude stability. Compared with a conventional thyristor-based solution, the proposed design exhibits faster current rise and better waveform quality, demonstrating the suitability of the proposed design for fast pulsed kicker magnet applications in advanced light sources.

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