# ADJUSTABLE PULSE DURATION FAST KICKER FOR THE CRYRING STORAGE RING

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*Abstract*

The CRYRING storage ring of the Manne Siegbahn Laboratory (MSL, Stockholm) shall be moved to become part of FLAIR accelerators complex in Darmstadt to be used for deceleration of antiprotons and charged ions. That needs an upgrade to adapt it to the full energy range (30Mev – 0.13 MeV) of its future exploitation

The development made specifically for the CRYRING kickers by SIGMAPHI in close collaboration with SOLEIL, is based on a new design involving two different pulsed power supplies, each one managing either the fast rise time or the current flat top. A solid state switch controls the triggering and also the pulse duration. This contribution presents the specific scheme and the development of a kicker system working up to 20 kV with pulse duration from 1.62 µs to 16.3 µs with transient times less than 280 ns.

## INTRODUCTION

Pulsed power is a technology that usually accumulates energy over a relatively long period and then releases it into a load within a short interval.

Energy stored in a capacitor is often used to obtain sine current waveforms in inductive magnet loads. PFL (Pulse Forming Line) or PFN (Pulse Forming Network) are classically exploited in trapezoidal current waveform generation.

The CRYRING injection system [1][2] must be able to provide a 3200 A trapezoidal current with 280 ns fall time and a fixed duration of 1.62 µs but the he extraction system requires a variable square current amplitude ranging from 3200 A to 200 A with a pulse duration varying between 1.62 µs and 16 µs and a rise time smaller than 280 ns.

Using a PFL-based circuit, the pulse duration dictates the length of the pulse forming line. For our extraction kicker, the 16 µs maximum pulse duration would impose more than 3 km long line. The superimposed need to tailor the impedance to the 12.5Ω characteristic impedance dictated by the 280 ns rise time either calls for specially made cables or to make a parallel arrangement of standard 50 Ω ones, resulting in prohibitive cable length and cost. In addition, the short rise and fall times and the strong current would require a high voltage close to 50 kV, that become delicate for many parts of the circuit like the HV switch especially if solid-state and coaxial cables. However, in PFL/PFN based circuits, this high voltage is an immediate consequence of basic requirements: the magnet directly determines the impedance of the forming line (or forming network) which in turn determines the voltage.

Due to the unusual requirement of the pulses generation with both strength and duration tuning, the development, made specifically for the CRYRING kickers [1][2], is based on a new topology involving two different power supplies, one managing the fast rise time and the other supplying the current flat top. A fast solid state switch controls the triggering and also the pulse duration. The idea of separating the functions is not completely new [3] but, to our knowledge, no pulser actually using it was ever completed and, the topology we propose is different from any of those defined in [3].

Table 1: Main parameters of MSL kickers

| System | Injection | Extraction |
|---|---|---|
| Estimated maximum current | Fixed 3560~ 3200 A | Adjustable 3200 A to 200 A |
| Kick rise Time (97% to 3%) | Not relevant | 280 ns |
| Pulse duration | Fixed 1.62 µs | Adjustable 1.62 µs to 16 µs |
| Flat top ripple | ≤ ± 3% | ≤ ± 3% |
| Kick fall Time (97% to 3%) | 280 ns | Not relevant |
| Pulse repetition | 2 s | 2 s |

## BASIC OPERATION PRINCIPLE

The circuit is described in Figure 1.

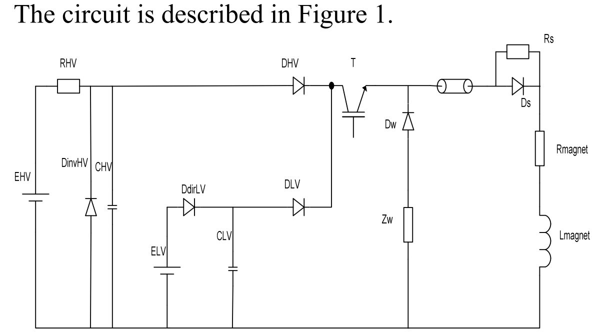


Figure 1: Kickers circuit schematics.

The kicker pulsed circuit associates a high voltage discharge circuit designed to provide the fast rise time, a large capacitor value that supplies the flat top high current and a free wheel circuit managing the current decrease duration. The kicker systems are built in such a way that the kick amplitude and pulse length are variable.




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Initially, the switch T is open. The capacitor $C_{HV}$ is charged through the resistor $R_{HV}$ to a voltage $E_{HV}$ in a time lower than the repetition time. The voltage across the capacitor $C_{LV}$ is maintained constant by the power supply $E_{LV}$.

At switch T closure, a resonant circuit is formed by the $C_{HV}$ capacitor and the $L_{magnet}$ inductance. A sinusoidal current starts rising in the inductive load, accompanied by a concomitant voltage drop in the high voltage capacitor. The current evolution is described by the simplified equation:

$$i_L(t) = E_{HV}\sqrt{\frac{C_{HV}}{L}}\sin\omega_1 t \qquad with\ \omega_1 = \frac{1}{\sqrt{LC_{HV}}}$$

L being the impedance and $\omega_1$ the resonant pulsation.

The rise time, defined as the time it takes for the magnetic field in the kicker magnet to rise from 3% to 97%, imposes the maximum permitted $C_{HV}$ capacitance

$$C_{HV} = \frac{1}{L}\left(\frac{100 * T_{rise}}{94}\frac{2}{\pi}\right)^2$$

This also determines the input high voltage source $E_{HV}$ needed to obtain the required maximum current amplitude

$$i_{LMAX} = E_{HV}\sqrt{\frac{C_{HV}}{L}}$$

Once the required peak current amplitude is reached, the $C_{HV}$ capacitor's voltage is near the $E_{LV}$ value and the diode $D_{LV}$ begins to conduct. After the overlap time between the $D_{HV}$ and $D_{LV}$ diodes, the low voltage circuit controls the flat top current in the magnet. During the flat top period, the low voltage constant source $E_{LV}$ delivers the current to the load. The knowledge of the circuit resistance (R) value gives the source constraint

$$E_{LV} = R \cdot i_{LMAX}$$

Once the pulse duration is achieved, the switch T is opened, and the fall time control is handed over to the free wheel circuit in which suitable choice of $Z_w$ components' value forces the load current to decrease in a predetermined duration, at the end of which the current is interrupted at the zero crossing by the opening of the $D_w$ diode.

## EVALUATION OF THE TOPOLOGY

The switching device plays an important role in the performance of the system, affecting rise time, jitter, and fall time and a specific printed circuit board based on multiple small fast IGBTs series-parallel association was developped. The advent of these new solid-state switches, exhibiting high-current and high-voltage capability to open or close the circuit with enough speed permits to avoid driving Thyratrons classically exploited in pulsed systems.

In the case of the extraction system, the resonant period of the discharge is very short, imposing an upper limit on the storing energy capacitance $C_{HV}$ (given that the magnet inductance is fixed) and so it demands charging voltages above 20kV to achieve the required peak magnet current, with consequent large and costly hardware. Although large, these voltage values remain within acceptable limits in comparison to the 50kV required in a conventional PFL topology.

One end of the magnet is connected to the pulsed positive voltage and the other end is connected to ground where the current is monitored using a Bergoz current transformer. This permits using coaxial cable from the high voltage pulsed power supply to the magnet to control the transmission impedance. Kick reversal is possible with a dedicated magnet interface.

To verify the performance of this circuit, a prototype able to be adapted to injection or extraction requirements has been built, tuned and tested.

Figure 2 gives a general view of the prototype pulser during assembly and Figure 3 gives a closer view on the high voltage switch in injection configuration.

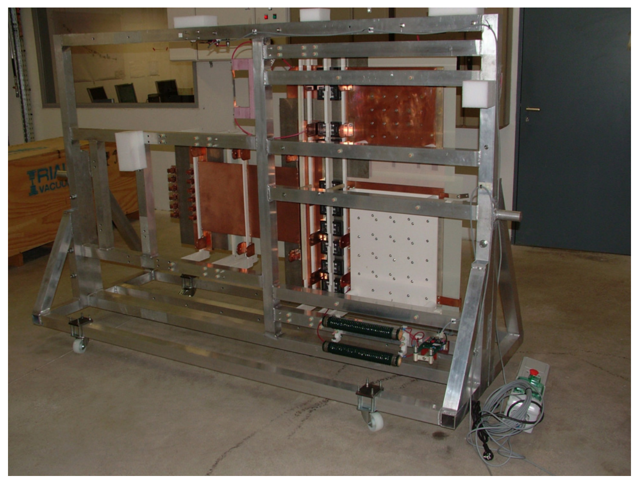

Figure 2: The prototype pulser during assembly.

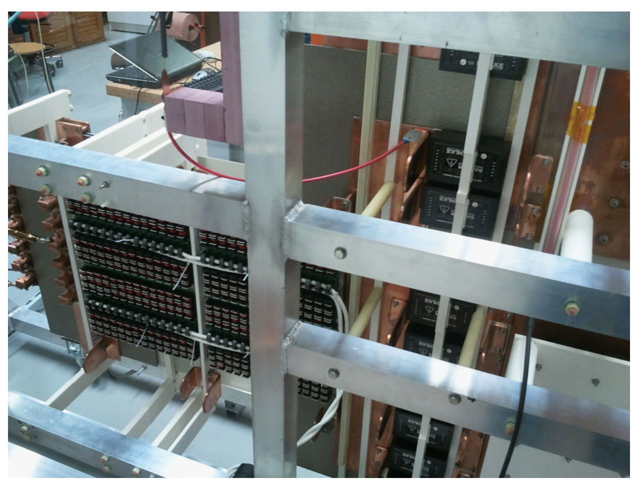

Figure 3: The HV switch in injection configuration.

## PERFORMANCES

To verify the performances, the prototype pulser is connected to an inductance representative of the kicker magnets.

### *Case of the Fully Tuneable Extraction Kicker*

The key parameters in the performances required for the extraction kicker are the $T_{rise}$ and the variability in pulse duration and amplitude.

With a small capacitor $C_{HV}$ value, we measure the curves shown in Figure 4, demonstrating the ability to respect the adequate performance near the nominal point.

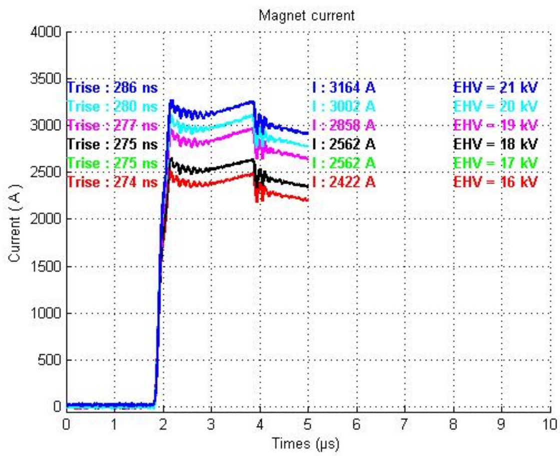


Figure 4: $T_{rise}$ measurement for the extraction kicker.

The measurements also permit to demonstrate the pulse width flexibility of the realisation, with full adjusting of the pulses both in amplitude and duration in all the required range (Figure 5). It is worth mentioning that in this case, where the falling time is not relevant, no effort is made to shorten the fall time of the pulse current and a simple diode is used as free wheel circuit. Shorter fall time could be achieved if needed.

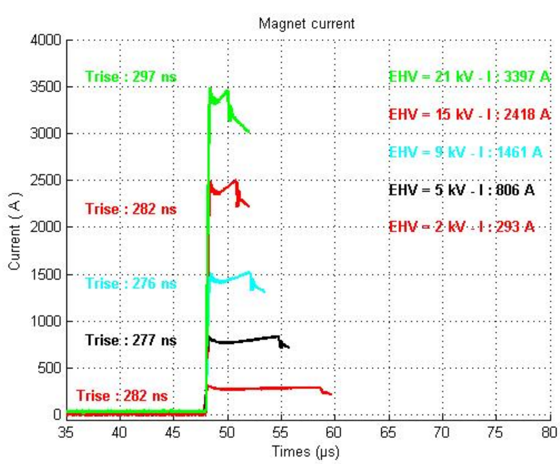


Figure 5: Variable pulse width and amplitude of the extraction kicker.

### *Case of the Injection Kicker*

The key requirement of the injection system is the fall time of the pulse current. The pulse duration and nominal amplitude are fixed. In a second arrangement of the prototype pulser, for the capacitor $C_{HV}$ a higher value is introduced to limit the high voltage requirement with an acceptable $T_{rise}$. Work was done to obtain the required $T_{fall}$ ($\leq$ 280ns) by an effort on the free wheel circuit adaptation. The injection kicker full pulse at 3660A is presented in Figure 6.

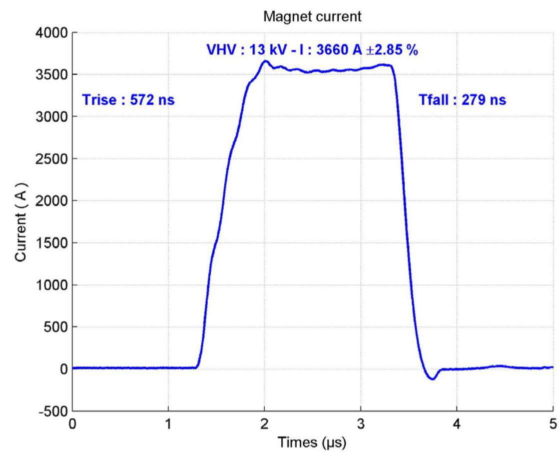


Figure 6: Injection kicker full pulse.

## CONCLUSIONS

The realization of these kicker magnets systems bring out the big advantages of this innovative scheme.

In the case of the extraction kicker, which has to accommodate non-relativistic beams of variable energy, from 130 keV to 30 MeV, it gives a very flexible solution in which both peak amplitude and width of the high current pulses can be adjusted, using only the two charging power supplies settings and the ON/OFF triggering times of the HV switch assembly.

Using available high current-high voltage switches, based on fast IGBTs, allows having a simple control of the pulse width and of the pulse triggering with low jitter.

For both injection and extraction kickers systems, this technology results in a much cheaper and much more compact solution than a classical PFL system.

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