Electrical Performance of the Injection System Kickers at the Saskatchewan Accelerator Laboratory *

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Abstract

This paper describes the results of upgrading the electrostatic kicker system at the Saskatchewan Accelerator Laboratory (SAL). The second of two kickers required for multi-turn injection into the Pulse Stretcher Ring (PSR) has been commissioned. Previously, with only one kicker, the injected beam duration was limited to slightly less than one pass around the circumference of the PSR. Multi-turn operation (up to three turns) enforced stringent field quality constraints and required a significant improvement in the electrical performance of the original kicker. After long-term operational experience the original modulator was upgraded and used as a model for the new assembly. The tandem kickers have successfully demonstrated multi-turn injection. Salient results of these investigations are presented.

I. INTRODUCTION

The Saskatchewan Accelerator Laboratory has recently commissioned the second of two kickers required for multi-turn injection into the Pulse Stretcher Ring (PSR). This injection process allowed the insertion of a one microsecond beam pulse into a 360 nanosecond long ring. In a previous paper, [1] the basic modulator design was discussed along with a brief summary of the early experience with the unit. Early investigations of factors such as average power, peak current, component stress, field quality, etc., and the engineering concerns of maintenance, reliability and lifetime led to the design of the original electrostatic deflector and compatible modulator.

The deflector plates shown in Figure 1 are 12 cm x 40 cm each and are separated by 3 cm within the vacuum tank. The kicker modulator is capable of producing field strengths of up to 26 kV/cm on the deflector assembly. This is accomplished by driving one plate positive and the other negative for a maximum differential of 80 kV. Normal operating repetition rates are up to 360 Hz. Pulses are generated by a slow charging circuit and a fast, high current shunt circuit. This modulator is characterized by its small size, low power (the main high voltage power supplies deliver only a few hundred watts) and simple layout. These features translate into an inexpensive and reliable system. A simplified schematic of the newest version of the modulator is shown in Figure 2.

The kicker operates by first charging the deflector plates using two identical triode circuits. These triodes are triggered

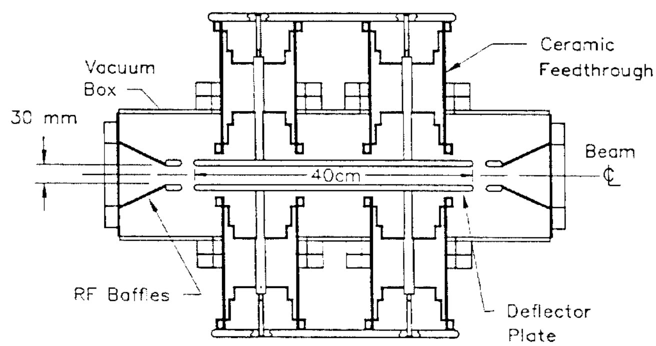

Figure 1. Deflector plate mechanical assembly.

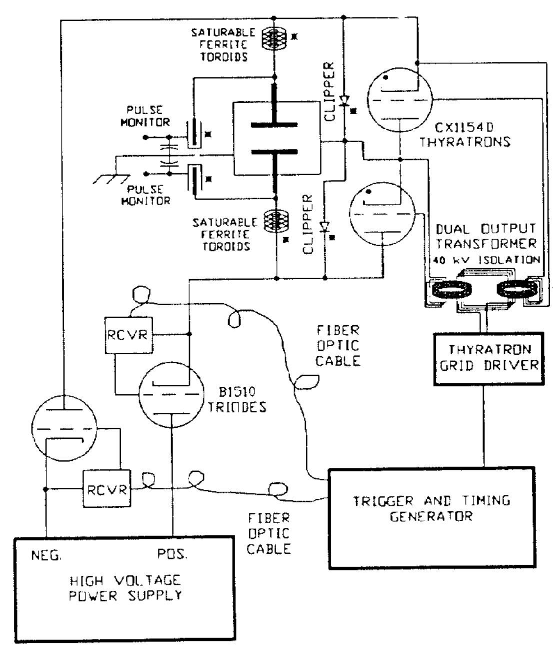

Figure 2. Simplified schematic of the kicker modulator. Filament and support circuits are deleted for clarity. Recent modifications are indicated by a *.

prior to the beam arrival. The pulse voltage is allowed to settle for approximately 100 μs to stabilize the "flat top" portion of the field pulse. The long charge time is not critical since there is no beam in the ring just prior to injection. After the deflector is fully charged, the triodes are disabled, fixing the plate voltages. The beam is then injected into the PSR and the thyratrons trig-

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gered so that as the tail end of the beam pulse passes into the kicker, the field begins to collapse. Ideally, the pulse should fall instantaneously to zero and remain there for the entire inter-pulse period. A typical field waveform produced by the kicker is shown in Figure 3. The field falltime is typically 20 ns.

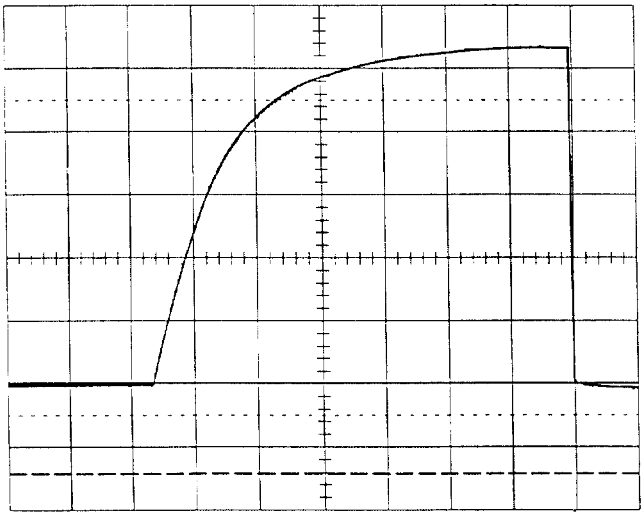

Figure 3. Typical field pulse showing charge period. Horizontal scale 20 µs/div, vertical amplitude of peak is 50 kV corresponding to 16.7 kV/cm deflector field.

After 18,000 hours of operation and occasional maintenance, several problem areas were identified. Before assembling the second kicker, the first modulator was modified to improve the performance, reliability, and remote adjustment features. These changes were as follows:

- Inexpensive high voltage pulse monitors with fast risetimes to aid diagnostics and tuning were developed.
- Improved the thyratron driver unit to provide matched triggers to each thyratron.
- Added saturable ferrite cores in strategic locations to limit trigger pulse coupling into the main deflectors and to sharpen the falltime of the pulse.
- Added clipper diodes to the thyratrons and to the extreme ends of the power supply circuits to limit reflection and undershoot of the pulses.
- Added grounding harnesses to "noisy" portions of the circuit and improved the enclosure to limit radiated interference.
- Converted the triode filament supplies to DC operation to stabilize tube gains.
- Improved triode and thyratron air cooling for better drift and jitter performance.

While using a single kicker, the injected beam was limited to slightly less than one turn around the PSR to allow for the finite falltime of the field. The second kicker allowed multi-turn injection by providing a kick to the head end of the beam pulse already circulating inside the PSR before it passed through the first kicker field on its second and third orbits. The result of this compensatory kick was to overlap the beam circulating in the PSR.

When using two kickers, the match between the two deflecting wave forms is critical. The technique depends on "exactly" correcting the kick of the first deflector with the second. The quality of the "exact" match determines the quality of the resultant stored beam.

II. UPGRADE RESULTS

The second kicker, which is an electrical twin of the upgraded original, was mounted downstream of the previous unit (with respect to the injected beam trajectory). The second modulator and its connections to the deflector assembly were mechanically copied as far as possible to provide the best match of stray circuit elements and in turn match the resulting pulses in time, amplitude and contour. The undershoot portion of the field was reduced as much as possible to achieve the best overall performance for both single and multi-turn injection. This allowed cleaner single kicker operation and, with a smaller error kick to contend with, simplified matching the two kicker response.

A pre- and post-fine tuning comparison of the original kicker pulse edge is shown in Figure 4. In Figure 5 the trailing edge of the improved pulse is expanded to show more detail. The dramatic effects appear in the collapsing portion of the pulse. As can be seen from the undershoot of the waveform in

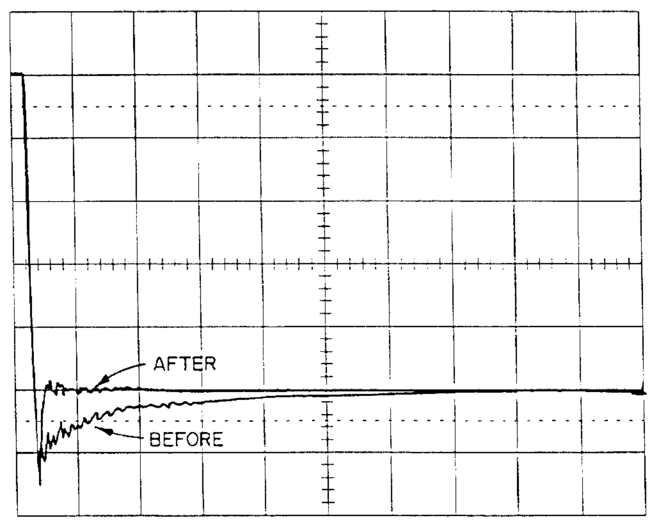

Figure 4. Typical field pulse before and after the upgrade. Peak amplitude is 16.7 kV/cm, horizontal scale 0.5 µs/div.

the earlier version, an undesirable kick was applied to the beam. Several sets of saturable ferrite inductors and clipper diodes were connected in various configurations in an attempt to "clean up" the basic waveform. The result was a significantly improved pulse, with the tail and undershoot portion of the field waveform reduced in amplitude and in time. This equated to a reduction of the erroneous beam deflection to about two percent of the previous value with no serious degradation of the 20 ns falltime. The ferrites also eliminated a small amount of trigger pulse coupling through the thyratron grids to the deflector plates. Previously, this caused a minor disturbance of the flat top

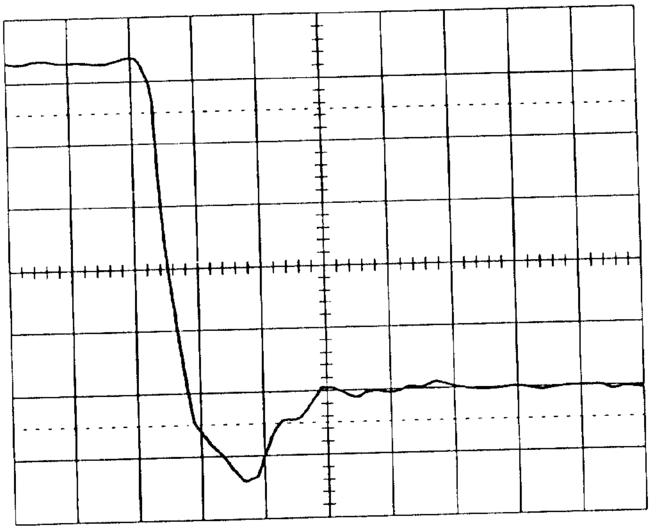

Figure 5. Typical field pulse after the upgrade. Trailing edge expanded to show region of scale 50 ns/div.

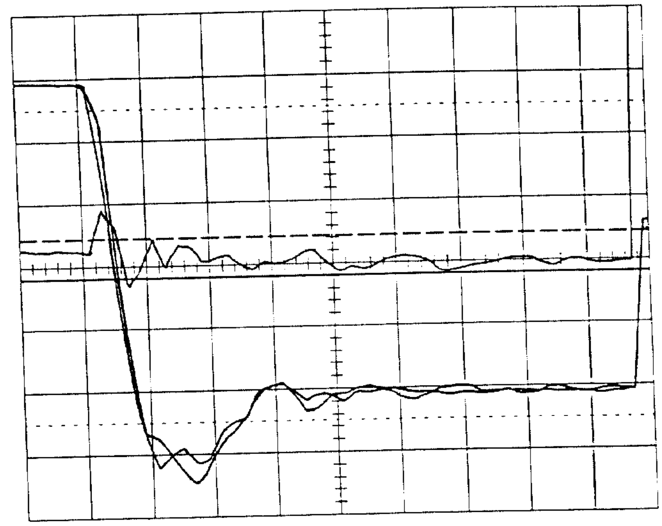

Figure 6. Comparison of the two different kickers. Field pulses aligned in time and matched in peak amplitude. Smaller amplitude central trace is the difference between the two fields (see note in text).

of the main deflector pulse for several hundred nanoseconds just before the field collapsed.

An improved driver system was incorporated to allow precision trimming of the firing times of the two thyratrons. A special high voltage isolating pulse transformer was developed. This transformer had a loosely coupled primary and a dual core, one for each secondary winding. While essentially two transformers in series, this design was adopted since the primary current was inherently the same around both cores. This geometry helped compensate for the differences caused by stray capacitance and leakage in a two transformer series layout which normally shunt away some of the current. The separated core structure had the best success ensuring that the trigger driven into each thyratron grid were closely matched in time and amplitude. This timing must be tightly controlled to achieve the highest possible collapse rates and reduce the ripple and overshoot on the electric field pulse. The driver allowed a single primary trigger pulse to drive both thyratrons while maintaining a relative timing adjustment range of approximately 50 ns. This was sufficient to compensate for short-term thyratron drift.

As a demonstration of the ability of this new layout to meet the matching requirements, a measurement was made of each kicker field and then the resultant waveforms were subtracted to yield the mismatch (or erroneous) field seen by the circulating beam (see Figure 6). This differential field translates into undesirable beam deflections. The four high voltage probes used to measure the relative voltages on the plates were matched to 2% in gain and had risetimes of 18 to 25 ns. Even without correcting the waveforms for probe variations, it appears that a field of only a few percent of peak exists for two to three hundred nanoseconds following the discharge. It should be noted that the first few cycles of the differential waveform are strongly affected by the alignment of the two falling edges of the main fields, emphasizing the need for accurate timing and identical shapes. Improvements can be made to this measurement by compensating for the individual probe responses.

III. CONCLUSION

The recent results of the kicker upgrade at SAL have been encouraging. The improved performance of the tandem kicker system in terms of pulse quality and ease of modulator adjustment should be adequate for the next series of PSR developments. Additionally, work continues on eliminating the residual undershoot remaining on the pulses. Future investigations will focus on correcting the high voltage probe differences, developing an automatic firing time drift compensator and linking the two kickers with a high level microprocessor controller. This should allow optimization of the relative timings between the two kickers and thus minimize beam disturbances.

IV. REFERENCES

[1] Curtis B. Figley, "A HIGH SPEED ELECTROSTATIC KICKER FOR THE PULSE STRETCHER RING AT SASKATCHEWAN ACCELERATOR LABORATORY," Nuclear Instruments and Methods in Physics Research, A273, pp. 59-62, 1988.