SLAC–PUB–5461
May 1991
(A)

Pulse Shape Adjustment for the SLC Damping Ring Kickers*

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Abstract

The difficulties with damping ring kickers that prevented operation of the SLAC Linear Collider in full multiple bunch mode have been overcome by shaping the current pulse to compensate for imperfections in the magnets. The risetime was improved by a peaking capacitor, with a tunable inductor to provide a locally flat pulse. The pulse was flattened by an adjustable droop inductor. Fine adjustment was provided by pulse forming line tuners driven by stepping motors. Further risetime improvement will be obtained by a saturating ferrite pulse sharpener.

I. KICKER REQUIREMENTS AND PROBLEMS

The SLAC Linear Collider (SLC) *e-* damping ring kickers must inject and extract 2 bunches on a single pulse, one for collision and one for *e+* production, to produce full collision rate. The two bunches are 60 nsec apart, and must receive the same kick to 10^{-3} or better. The pulser risetime is marginal, and in addition the multigap thyratrons required for high voltage and fast rise time produce a series of prepulses as the gaps break down. Neither of two different magnet designs has produced a field pulse with the desired risetime and flatness for 2 *e-* bunch extraction [1]. These problems combined to prevent operation with 2 bunches in the *e-* damping ring, allowing only half of the linac pulses to be used for collisions, with the other half used for *e+* production. A program to produce a better magnet was undertaken, but progress was expected to be slow because the magnet faces additional constraints from size, high voltage, and radiation damage [2]. A parallel program was therefore undertaken to control the pulse shape.

II. SHAPING WITH LUMPED COMPONENTS

The e- extraction kicker pulser [3] uses 2 thyratrons in an oil filled tank to switch charged cables at the anodes into output cables at the floating cathodes to the magnet and its terminating load. Each thyratron switches 2 parallel 50 ohm cables, and 4 cables are paralleled at the magnet. The first method of pulse shaping was to connect inductors ("droop coils") from the cathodes to ground. The L/Z time constant was chosen so the droop in the current would approximately compensate for the rise in field due to magnet mismatch. Adjustment was provided by using a clip lead to short varying numbers of turns. The droop coils succeeded in producing equal field amplitudes for the 2 bunches, but only for a unique kicker pulse timing, which was so early that the second bunch received a significant kick on the turn before extraction.

While inductors reduce the current late in the pulse, capacitors can add current early in the pulse. A capacitor in parallel with the charge line would produce a 100% overshoot in the current, with a decay time constant fixed by the capacitor value, for ideal capacitors and switches. Experiments showed that the ZC time constant must exceed the thyratron rise time for any effect to be observed, and the di/dt is not improved even for large capacitor values, presumably being limited by the thyratron and inductances. For threshhold capacitor values the current does not overshoot but does reach the flattop value sooner. Larger values cause some overshoot (but much less than 100%) and the expected increasingly long tail. The amount of overshoot depends on the voltage, presumably because the thyratron risetime depends on voltage. Series inductance causes some ringing, but some inductance actually increases the overshoot for intermediate capacitor values by delaying capacitor discharge until the thyratron is more fully conducting. Inductance also reduces the sensitivity of the overshoot to voltage and risetime.

Ceramic capacitors were connected from thyratron anodes to ground in parallel with the charge line cables with short wires, and the capacitor value was varied for optimum performance. For large values a local maximum field early in the magnet pulse could be created, which provided a unique flat spot for the more critical first *e-* bunch, and which was early enough to avoid a large kick to the other bunch on the previous turn. The droop coil clip leads were then used to make the amplitude equal at the time of the second bunch 60 nsec later. This configuration produced a magnet pulse that was sufficiently close to ideal that 2 *e-* bunch SLC operation and 120 Hz collisions were achieved in January 1990.

Ideally the shape of the current pulse could be adjusted to make not just a local maximum in the field but a flat region of finite duration. The ideal value capacitor depends on the thyratron risetime, and 80 KV variable capacitors are not easily constructed. An alternative is a fixed capacitor with a variable inductor in series. The inductor is a short coaxial line

* Work supported by US Department of Energy contract DE-AC03-76SF00515

Presented at the IEEE Particle Accelerator Conference, San Francisco, CA, May 6–9, 1991

constructed of copper pipe and rod and immersed in the thyratron tank oil, with its center conductor attached to the capacitor and outer conductor to ground. A piston with contact fingers provides a sliding short to vary the inductance. By adjusting the piston, the dB/dt can be made not only to cross zero (for a local maximum), but to be tangent to zero (for a local flat spot). Figure 1 shows this has not quite been achieved, but soon a remotely controlled version of the piston tuner should make it possible.

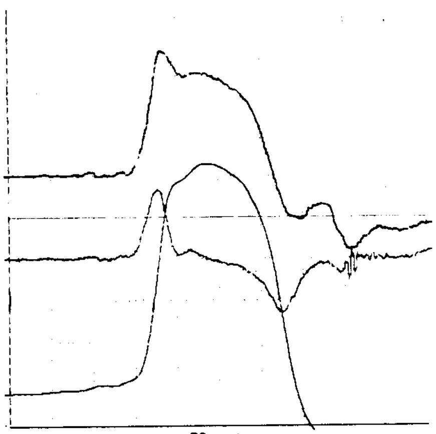

Figure 1. From top to bottom, shaped current pulse, dB/dt, and B(t) pulse.

III. ROTARY PULSE LINE TUNER

While current pulse shaping with lumped components can compensate roughly for magnet imperfections, making the adjustments requires trial and error with multiple interruptions of operations, and the proper correction would not necessarily be stable anyway. We have therefore constructed additional pulse shaping devices to provide continuous remote control of the relative *e-* kick amplitudes necessary to put the second *e-* bunch on the same orbit as the first.

The rotary pulse line tuner is designed to change the amplitude of the second bunch kick without disturbing the first bunch, and without introducing any slope to the pulse. This decouples the amplitude equality problem from the zero slope problem. The tuner is a short variable impedance transmission line inserted into the charge line cables at a distance from the thyratron. The discharge wave launched by the thyratron produces a reflection from the mismatch at one end of the tuner, and the transmitted wave produces an opposite and nearly equal reflection from the other end. The two reflections travel to the magnet where they sum to a bump of duration determined by the tuner length. The amplitude can be positive or negative depending on the mismatch, or zero if the tuner impedance is set to the line impedance. If the tuner is placed at the proper distance from the thyratron, the first bunch is not affected, and the second bunch is at the local maximum or minimum of the bump, so no slope is introduced.

The tuner high voltage conductor is a slice of 8 inch aluminum pipe, and the ground conductor is a 6 inch aluminum pipe cut in half, concentric with a .5 inch separation. They form a parallel conductor transmission line whose impedance can be varied by rotating the ground conductor. The high voltage stator is mounted on plastic standoffs approximately at the center of a 12 inch aluminum pipe, and the rotor is mounted on bearings and grounded to both end plates with sliding fingers. There are 2 RG-220 cable connectors on each end plate, and a stepping motor and readout pot on one end. One 6 foot tall oil filled tuner tank is required for each of the 2 thyratrons of the *e-* extraction pulser.

Initial scale model tests indicated that connector inductance could introduce a dip into the pulse, so the stator comes within .5 inch of the ends. The stator was also originally 180 degrees wide, giving a large maximum capacitance to the rotor that could overcome any dip. The dip in production tuners proved to be negligible, but the extra stator width caused stray capacitance to the outer pipe that made the tuning range only positive and not negative. The stator was later narrowed to 90 degrees making the range bipolar. Figure 2 shows the maximum excursion from a flat pulse is over +/- 10%, with very little perturbation at the neutral position.

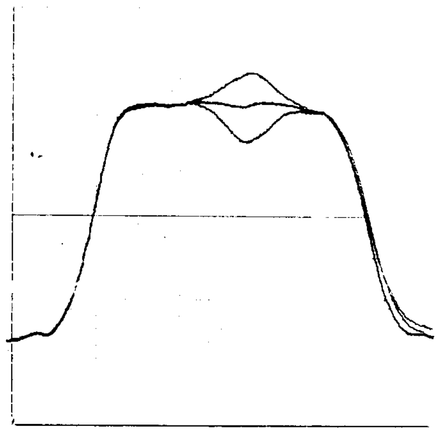

Figure 2. Current pulse at 3 rotary tuner positions

The stator operates up to 80 KV, and some arcing has occurred, mostly from the stator to the end plates, and sometimes tracking along the Delrin standoffs. Carbon tracks on the 2 inch long standoffs were traced to a layer of internal air bubbles in the raw material, apparently common in extruded Delrin. New standoffs have been made from porosity-free cast Delrin. The tuners have operated for many months with no arcs, but clearances in the tuner are small enough that air bubble, water, or other contamination of the oil can promote arcs. Arcs have caused no damage to the tuners but have destroyed charging diodes in the pulser. When one tuner arcs it applies large forward currents to its own diodes, and reverse voltage to the diodes on the other tuner. Using a single diode string to charge both tuners, protected by a large inductor and capacitor, with smaller inductors to isolate the thyratrons during normal operation, has solved this problem.

IV. Saturating Ferrite Pulse Sharpener

Neither the lumped components nor the rotary tuners address the problem of thyratron prepulse, or poor risetime, which cause the second *e-* bunch to be kicked slightly on the turn before extraction. This cannot be corrected on the final turn because the previous turn kick is at a different betatron phase. We have developed a small pulser described elsewhere [4] to cancel the prepulse at the magnet, which in combination with the rotary tuner allows the 2 bunch orbit difference requirement to be met. However, the preferred solution is to stop the prepulse at its source. We have suceeded, not only reducing the prepulse below the required level but also dramatically improving the current pulse risetime.

It is relatively common to use saturating ferrite cores to improve the rise time and reduce the commutation losses of thyratrons. Cores placed over the RG-220 output cables directly at the thyratron were found to only attenuate the prepulse by a roughly a factor of 2, and not improve the risetime, even though they had far more volt-seconds to saturation than in the observed prepulse and the early part of the rise. This was because the small amount of charge released by the prepulse raised the voltage across the ferrite to essentially the full thyratron anode voltage, which saturates the ferrite before the thyratron becomes fully conducting. There is also an equivalent shunt resistance across the ferrite cores. When a very fast voltage pulse is applied to a core, there is not only a linear rise in current to saturation, but also a prompt current approximately proportional to the voltage. This is simply the time domain manifestation of the ferrite loss tangent. Typical loss tangent vs frequency information is consistent with a simple model for an ungapped ferrite core of a shunt resistance in parallel with the unsaturated inductance that provides a time constant of a fraction of a nanosecond. For our core experiment, the resistance was comparable to the system impedance, so the prepulse was only cut by half.

This model predicts that changing the core geometry to increase the unsaturated inductance while keeping the volt-seconds to saturation constant will increase the resistance proportionately, i.e., the resistance is inversely proportional to ferrite volume at fixed cross section. This was tested by making simple inductors with 1 turn on 4 cores, 2 turns on 2 cores, and 4 turns on 1 core. The saturation volt-seconds were the same, but the 1 core inductor, with 4 times the inductance, had 1/4 the resistive current as well as 1/4 the di/dt.

Simply adding turns to a single core also increases the saturated inductance, which would increase the system rise time. The optimum solution is to make a ferrite filled coaxial structure, which has the maximum inductance and thus shunt resistance for a given volt-second saturation level, and also can be designed to match the system impedance when saturated. It should be located far enough from the thyratron that reflections do not return until the ferrite is saturated.

We tested a ferrite loaded coaxial line remote from the thyratrons and found that it transmitted no measurable prepulse, and also improved the main current pulse rise time to less than 10 nsec, as seen in Figure 2. The production device uses 20 CMD-5005 nickel-zinc cores, each 1 inch long, 1 inch ID, 1/16 inch wall thickness, on a 1 inch ID aluminum tube. The thin ferrite wall thickness was chosen to maximize the ferrite switching speed. The ferrite is separated from am outer aluminum tube by 1/8 inch of flowing oil. Enlarged ends contain chokes to either reset the ferrite (which has not proven necessary), or to pre-saturate it (to remove the pulse sharpening effect). The ends also each contain 4 RG-220 cable connectors, and the oil flow connections. It has been operated at up to 40 KV with no damage from arcs, and no arcs when the oil is flowing.

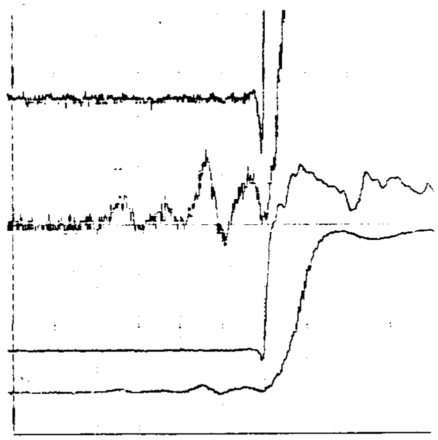

Figure 3. From bottom to top: thyratron output pulse, pulse sharpener output pulse, thyratron pulse amplified by 10 to emphasize prepulse, and same for sharpener output.

V. References

[1] R. Cassel et al., "SLC Kicker Magnet Limitations," in *Proc. of 1991 IEEE Particle Accel. Conf.*, San Francisco, CA, May 1991.

[2] T. Mattison et al., "Operational Experience with SLC Damping Ring Kicker Magnets," in *Proc. of 1991 IEEE Particle Accel. Conf.*, San Francisco, CA, May 1991.

[3] L. Bartelson et al., "Kicker for the SLC Electron Damping Ring," in *Proc. of 1987 IEEE Particle Accel. Conf.*, Washington DC, March 1987, pp. 1582-4.

[4] R. Cassel and T. Mattison, "Kicker Prepulse Canceller," these proceedings.