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Design and Performance of the Traveling-Wave Beam Chopper for the SSRL Injector*

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Abstract

A pulsed, split-parallel plate chopper has been designed, built, and installed as part of the preinjector of the SSRL Injector. Its function is to allow into the linear accelerator three consecutive S-band bunches from the long bunch train provided by a RF gun. A permanent magnet deflector (PMD) at the chopper entrance deflects the beam into an absorber when the chopper pulse is off. The beam is swept across a pair of slits at the beam output end when a 7 kV, 10-ns rise-time pulse passes in the opposite direction through the 75 Ω stripline formed by the deflecting plates. Bunches exiting the slits have their trajectories corrected by another PMD, and enter the linac. Beam tests demonstrate that the chopper functions as expected.

I. INTRODUCTION

The SSRL Injector[1,2] is unusual in that it uses a microwave or RF electron gun[3] rather than a conventional DC gun. Details of the gun and the gun-to-linac transport are reported elsewhere[4,5,6]. For the present, we simply review some of the main features.

The RF gun was designed in collaboration between SSRL, Varian Associates, and AET associates, and consists of a thermionic cathode mounted in the first half-cell of a $1\frac{1}{2}$ cell side-coupled, velocity-of-light standing wave cavity. Because the cathode is thermionic, a beam is produced as long as RF is supplied to the gun (after the cavity fields have built up sufficiently). The average beam momentum is typically 2 MeV/c.

The RF frequency of the gun is 2856 MHz, while that of the booster accelerating cavity is 358.54 MHz. Three to five RF gun bunches can be captured in any RF bucket of the booster. One potential operating mode is to fill many consecutive booster buckets with three gun bunches each. These bunches would then be accelerated together in the booster and injected into SPEAR in a train, filling the same number of consecutive buckets in the storage ring. Such an approach is more complicated than filling a single booster bucket with three bunches. In addition, if one fills only one booster bucket, one can obtain arbitrary filling patterns in SPEAR by filling different booster RF buckets on different booster cycles. Hence, it was decided to design a chopper that would fill only a single booster RF bucket per booster cycle.

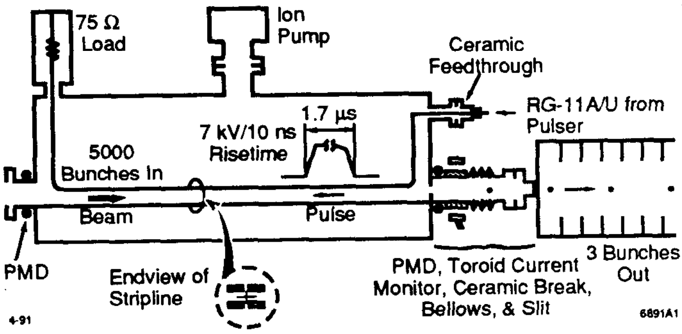

Figure 1. Side view of the chopper.

Following the gun is the gun-to-linac (GTL) transport line, which consists of five quadrupoles, steering magnets, an alpha-magnet[6,7], diagnositic instrumentation, and the chopper. A diagram of the GTL appears in another paper in these preceedings (see Fig. 1 of [2]). The combined optics of the quadrupoles and alpha-magnet is required to produce sufficiently small vertical beam sizes at the end of the chopper for proper chopper operation, while simultaneously fitting the transverse phase space for both the horizontal (x) and vertical (y) planes into the acceptance of the first linear accelerator section.

II. PRINCIPLE OF OPERATION

The RF pulse is $\approx 2\,\mu s$ long and the gun charging time constant is $\approx 0.3\,\mu s$, so that the gun emits $\approx$ 5000 bunches per RF pulse. Since only about three of these bunches are to be used, the beam hits an absorber until it is time to kick the beam into the linac. As seen in Fig. 1, the chopper incorporates two permanent-magnet deflectors (PMDs), one before and one after the pulsed portion of the chopper. The pulsed element in the chopper is a split parallel plate transmission line enclosed in a evacuated cylindrical pipe. The deflection caused by the first PMD results in the beam hitting the water-cooled, copper, downstream endwall of the chopper tank. It can easily be seen that the Lorentz forces on a relativistic beam, due to transverse electric and magnetic fields of a TEM wave, cancel if the wave and beam travel in the same direction and add if in opposite directions. Therefore, when the chopper is pulsed at the desired time, the steep, nearly linear, rising edge of a pulsed TEM

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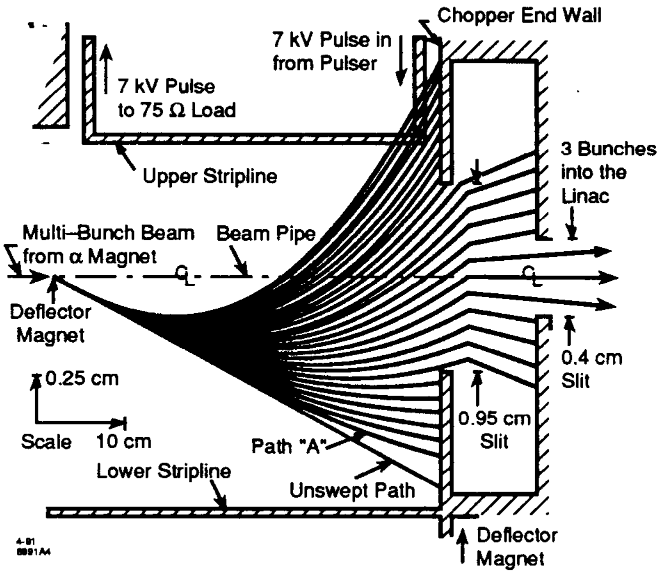

Figure 2. Beam bunch trajectories through the chopper. Path "A" is ≈ 1.3 ns into the pulse, when the pulse has filled the stripline. Subsequent paths are 350 ps apart until the 7 kV pulse peak is reached after ≈ a 10 ns risetime.

wave is launched upstream on the stripline-like structure and causes the beam to be swept across an opening in the absorber. The choice of a 40 cm long, 75 Ω stripline allowed the pulser voltage, its rise time, which is less for a larger impedance, and the alpha magnet to linac distance to be kept reasonable. Those bunches that pass through the 9.5 mm opening in the absorber are deflected by the second PMD so that they are traveling with nearly zero slope, but still continue to diverge slightly. Further filtration of these bunches occurs at the 4 mm slit just before the first linac cell. The vertical, angular divergence of the bunches is partially taken care of by longitudinal acceleration and quadrupole focussing in the linac, all of which, when taken together, determine the acceptance of the linac. Furthermore, it can be shown that the vertical separation, x, of the bunches at the output end of the plates is given approximately (with a few fudge factors and constants left out here and there) by: $x \,\alpha\, V_0\, l^2(1+\beta)/(g\, f_0\, t_r\, p_z)$, where V_0 is the peak voltage of the pulse, l is the plate length, β is the normalized relativistic velocity of the beam and comes from the magnetic field contribution, g is the plate gap spacing, f_0 is the microwave frequency that determines the bunch spacing, t_r is the pulse's linear risetime from 0 to V_0 and p_z is the longitudinal momentum of the beam. These points are illustrated in Fig. 2.

Experimental confirmation that the chopper works as planned has been obtained by viewing the beam on a phosphorescent screen at the end of the linear accelerator. With appropriate adjustment of the optics, the bunches can be dispersed vertically on the screen, rather than focussed as usual. Depending on conditions such as the beam energy from the gun and tuning of the GTL optics, three to five dominant bunches are seen, as shown in Fig. 4, with several very low intensity bunches before and after. This is in good qualitative agreement with simulations done using the tracking program **elegant**[8].

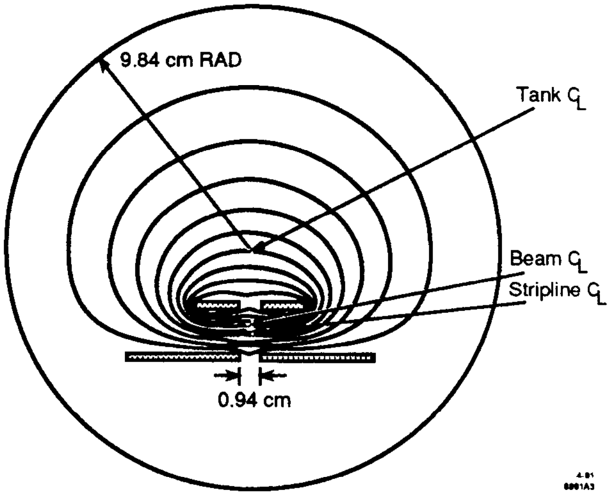

Figure 3. Cross section of the chopper tank showing the parted stripline and the electric field equipotential lines. Note that the field is less in the midplane than between the plates. The plates are split in order to lessen interception by the vertically sweeped beam. The lower plate is grounded at each end. The beam centerline (before and after the chopper and its deflection magnets), is 3.18 cm below the tank centerline. The stripline centerline is 3.43 cm below the tank centerline and the stripline plate spacing is 1.84 cm.

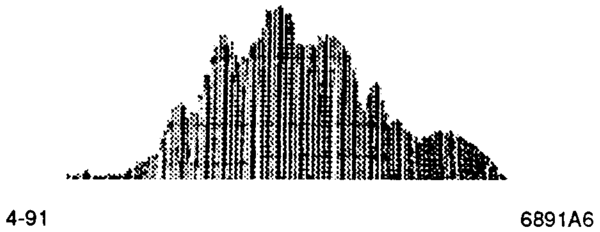

Figure 4. Three plus bunches at the end of the linac as the chopper culls them from the output the microwave gun.

III. DESIGN OF THE STRIPLINE AND TANK

An electrostatic analog and the program `estat` were used, instead of such a standard code as `Poisson`[9], to solve Laplace's equation in two dimensions for a TEM mode on the stripline in the chopper tank. Time domain reflectometry was used to verify that the impedance of the finished stripline in the task is indeed 75 Ω. Figure 3 shows a cross-sectional view of the chopper tank and plates, along with equipotential lines for the electric field.

The upper plate is bent upwards by 90° at each end, continuing the transmission line with the end-walls of the chopper serving as the ground plane. This continues until just before the plate joins to the feedthroughs, so that impedance mismatches are avoided. The feedthrough on the upstream end of the chopper tank is terminated by a column of resistors with a total resistance of 75 Ω.

The column consists of eight in-series groups of six, 56 Ω, 2 W, carbon resistors in parallel, roughly forming a cylin-

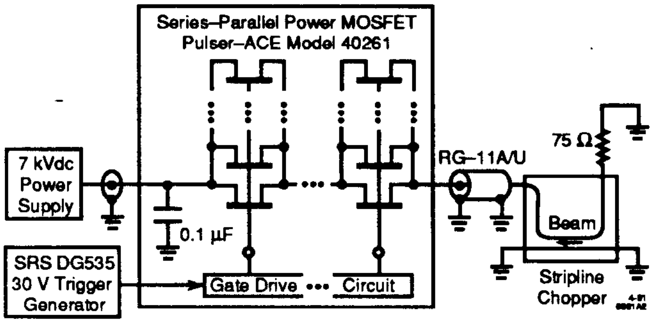

Figure 5. Simplified circuit of the pulser, stripline chopper and 75 Ω Load

der or tube. Around this column is a hollow aluminum cylinder that is grounded to the chopper tank at the bottom, and connected at the top by a metal disk to the end of the resistive column. The inside diameter of the aluminum cylinder and the diameter of the resistive column are such as to form a coaxial transmission line with an impedance of roughly 75 Ω. A small resistor inserted near ground in the resistive column provides a 1:1000 signal that can be viewed on an oscilloscope.

IV. DESIGN OF THE MOSFET PULSER

The pulser was designed and built by American Control Engineering. It consists, as shown in Fig. 5, of a 0 to 7 kV variable voltage power supply, a high voltage storage capacitor and a fast MOSFET switch. The latter is the heart of the pulser and consists of a gate driver circuit and ten paralleled strings of twenty power MOSFET packages in series. The switch is used to generate a fast risetime (10 ns), short (1.7 μs), capacitive-discharge pulse that passes through the 75 Ω chopper tank to its 75 Ω load.

The MOSFET's fast and relatively clean on and off power switching capability is the result of significate advances in technology since its introduction in 1975. Basically, a power MOSFET uses VLSI technology to get up to $3 \times 10^5/\mathrm{cm}^2$ selfblocking, field-effect transistors on a die with a gate, a source and a drain connection to the outside of a typical TO-220 package. If a voltage is applied between the gate and the source, the drain to source resistance drops dramatically. When this voltage is removed, the resistance increases equally quickly, typically in ≈ 2 to 4 ns at the chip level, since there is no storage time due to minority carriers as in conventional bipolar transistors. The turn-on speed is affected by the gate to source capacitance as well as by the smaller drain to gate capacitance. The latter is multiplied by an effect akin to the Miller effect; thus, for fast turn-on the gate drive source impedance must be low. As always with fast and especially high power switching circuits considerable care must be taken in the detailed circuit design and packaging. For this pulser proprietary topology plus carefully selected and matched components provide for uniform current sharing among the individual parallel MOSFET devices, both during turn-on and turn-off as well as during the switching process. Spurious oscillations of the MOSFET devices are eliminated by a combination of series gate resistances and Q spoiling ferrite beads surrounding each of the gate connection leads.

Voltage grading of the series connected stages is required in order to ensure that the voltage rating of each of the individual stages is not exceeded when the switch is off. This grading is provided by high speed zener diodes that are connected in parallel with the MOSFET devices. These diodes also absorb the energy that has been stored in the switch assembly inductance during the turn-on time and is released during the turn-off process. The design is such that one or two failed stages will not generally cause unsatisfactory operation of the switch stack, provided that the diminished voltage rating is not exceeded.

Typical individual power MOSFET devices can operate at 50 to 1000 V and switch 1 to 100 A in 5 to 10 ns at megahertz rates with 0.01 to 1.5 Ω turned-on resistances. They are very rugged and reliable and can be seriesed and paralleled as was done in this case. This unit has operated reliably and well for nearly a year in spite of some customer supplied cable connection arcing problems.

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