The SSRL Injector Kickers*

H.-D. Nuhn, R. Boyce, J. Cerino, T. Hostetler
Stanford Synchrotron Radiation Laboratory, P.O. Box 4349, Bin 69, Stanford, CA 94309-0210

Abstract

The kicker units for injection and ejection at the new *SSRL* Injector Synchrotron are built from two kicker modules driven by compact in-air delay line thyratron pulsers. The kickers have an aperture of 25 mm×60 mm. The injection kicker is 60 cm long (30 cm each module) and bends the 150 MeV electron beam by 42 mrad during injection. The extraction kicker module is 120 cm long (60 cm each module) and bends the 3 GeV beam by 4 mrad for extraction. The pulsers produce current pulses in the order of 900 A with a fall time of 200 nsec for injection, a rise time of 260 nsec for extraction and a pulse length (rise plus flat top time) of 400 nsec.

I. Introduction

SSRL, the Stanford Synchrotron Radiation Laboratory successfully commissioned a new injector for the SPEAR electron storage ring in Summer and Fall of 1990[1].

SPEAR originally built as an electron-positron storage ring for high energy physics collider experiments by *SLAC*, has been used during the last 15 years parasitically as well as in dedicated operation for synchrotron radiation experiments. SPEAR was handed over to *SSRL* in October 1990 after the high energy physics program was terminated.

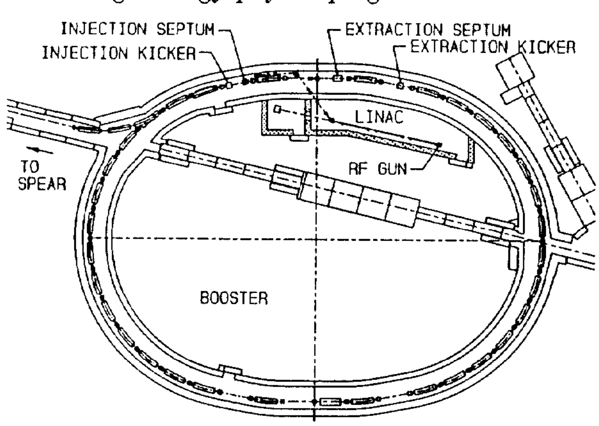

Figure 1
Booster Ring and Kicker Positions

The new injector includes a 2 MeV thermionic RF gun, a 150 MeV electron linac and a 3 GeV booster synchrotron with a 445 nsec revolution time. The main magnets (Dipoles and Quadrupoles) are operated in a White circuit configuration at a 10 Hz repetition rate [2].

Injection as well as ejection is done by a combination of a single kicker unit and a septum magnet, because the booster is designed to accelerate either a single bunch or bunch trains of a length of up to half the circumference of the booster. In the single bunch mode the bunch will be created by filling 3 or more linac bunches into one booster bucket in one shot.

Fig. 1 gives a rough layout of the site and shows the location of the injection and ejection kickers.

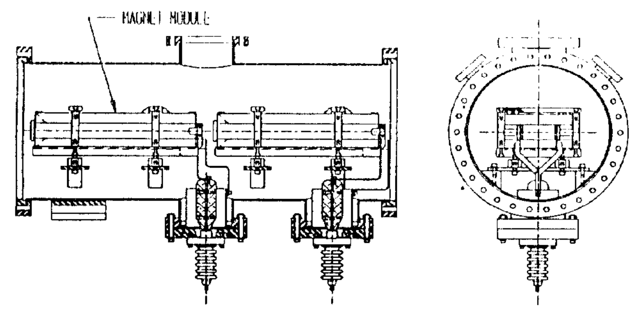

Figure 2
Schematic of the Injection Kicker

The injection kicker has to change the path of a train of three or more S-band bunches (2.856 GHz), that are singled out by a chopper from the bunch train out the gun [3], by 42 mrad at 150 MeV.

The ejection kicker has to bend one 3 GeV bunch by about 4 mrad.

The triggers for the kickers are prepared, based on a biased peaking strip in a booster magnet, by a timing and trigger system that provides phase coupling to the White circuit as well as to the phase of the selected SPEAR RF bucket [4].

Tab. 1 lists the basic parameters of a kicker module.

Table 1
Parameters of a Kicker Magnet

Length (Inj.)	300	mm
Length (Ej.)	600	mm
Gap Height	25	mm
Gap Width	60	mm
Conductor Thickness	60	mm
Required Kick Angle (Inj.)	42	mrad
Required Kick Angle (Ej.)	4	mrad

II. Magnets

The injection and ejection kicker modules each are made of two submodules (kicker magnets). Each kicker magnet is made from ferrite blocks, that form an H-frame around a copper winding. The assembly is held in place by an aluminum support structure and located in stainless steel vacuum tanks. Fig. 2 shows the layout of a ferrite magnet.

*Work supported by the Department of Energy, Office of Basic Energy Sciences, Division of Material Sciences.

0-7803-0135-8/91$01.00 ©IEEE

The ejection kicker magnets have double the length of the injection kicker magnets but are of the same design. The ferrite blocks are of CMD5005 material (from CERAMIC MAGNETICS), which is a high μ NiZn ferrite.

III. PULSE GENERATOR

A. Circuit Description

Each submodule of each kicker (injection as well as ejection) is pulsed independently from a 'Delay Line Pulser' as shown in fig. 3. The two submodules, forming one kicker, are triggered simultaneously and they are charged from the same HV power supply. The Pulse Forming Network (PFN) and a peaking capacitor is charged by the HV DC power supply, capable of up to 30 kV, via a 470 kΩ charging resistor. The PFN is made of two 50 Ω coaxial cables

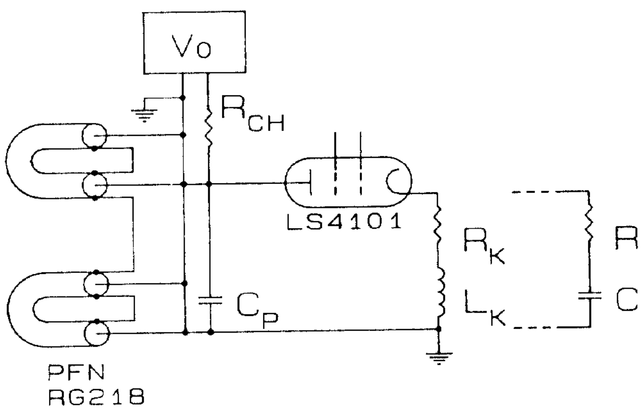

Figure 3
Circuit Diagram of the Injection Kicker Pulse Generator

with the center conductors and the shields, respectively, of the four ends connected to each other. Each PFN cable is 80 m in length to produce a 400 nsec lasting current pulse. The kicker pulse is initiated by a trigger to the EG&G #LS-4101 Hydrogen Thyratron. Most of the PFN charge is absorbed by the 12.5 Ω load resistor that is in series to the kicker magnet. Part of the pulse is reflected back into the PFN. The current I_K through the kicker and the load resistor is described by

$$\frac{d^2 I_K}{dt^2} + 2\beta\frac{dI_K}{dt} + \omega_0^2 I_K = \frac{2V_+}{L_K C_P Z_0}$$

with $\beta = \frac{1}{2}[\frac{R_K}{L_K} + \frac{1}{Z_0 C_P}]$ and $\omega_0^2 = \frac{1}{L_K C_P}[1 + \frac{R_K}{Z_0}]$. The forward voltage V_+ is either half the charging voltage V_0 during the rise time and the pulse top duration or, during fall time, the voltage that had been reflected during the rise time of the pulse. We are operating with a load resistor impedance R_K, that matches the PFN characteristic impedance, Z_0, i.e. $R_K = Z_0$. The capacitance of the peaking capacitor can be expressed as $C_P = L_K/(R_K^2 f)$. For critical damping one gets a value for the factor f of 5.82. To achieve the smallest variation in current at the top of the pulse one needs to work slightly above critical damping, i.e. a smaller value of f. The risetime, for an increase in amplitude from 0-95%, approximately $3/\beta$ is then given by $\tau = 6L_K/(R_K[1+f])$.

This circuit provides a rapid rise time and a fairly fast fall time. The fall time is longer than the risetime because it is driven by the reflected pulse that is decaying toward zero volts. The fall time could be be shorted by removing the load resistor R_L as done by Gabor et al. [5]. The decay of the pulse amplitude is then driven by the reflected voltage going toward $-V_0$. The pulse is shut off by the thyratron when the current is going to become negative. With such a circuit modification rise and fall time would be approximately equal. With critical damping the risetime would be about 60 % larger than that in the unmodified circuit (f = 4.0) Disadvantages of that circuit are high negative voltage amplitudes in the PFN cables as well as high reversed voltages across the thyratron tube, possibly lowering the life time of these components.

Fig. 3 also shows an option to put an RC combination across the kicker magnet and the load resistor. This helps to filter higher frequency components from the kicker pulse and to lower reverse voltages across the thyratron. It causes a deterioration of the current pulse, though. Tab. 2 lists the basic parameters of a pulse generator. The ejection parameters are refer to the circuit with the RC compensation included.

Table 2
Parameters of the Pulse Generator

Repetition Rate	10	Hz
Injection		
PFN Voltage 150 MeV	20.9	kV
Flat-Top Top Current	836	A
Rise Time (5% to 95%)	120	nsec
Flat-Top Duration	260	nsec
Fall-Time (95% to 5%)	200	nsec
Ejection		
PFN Voltage 3.0 GeV	20.1	kV
Flat-Top Top Current	804	A
Rise Time (5% to 95%)	260	nsec
Flat-Top Duration	190	nsec
Fall-Time (95% to 5%)	300	nsec

B. Thyratron Auxiliary Supplies

The cathode as well as the anode of the thyratron are at a potential difference of $V_0/2$ against ground for the duration of the kicker pulse. The auxiliary voltages and control signals have to be supplied while keeping the anode and grid potentials separated from ground potential. In this case all signals required to operate the thyratron (i.e. cathode heater current, reservoir heater current, grid bias and trigger voltages as well as auxiliary grid voltage) are generated by a commercial device from IMPULSE ENGINEERING INC. operating at ground potential. The potential separation during the duration of the pulse is done by magnetization of a ring ferrite in the following way: The cables required for the transmission of the auxiliary voltages as well as diagnostic cables from the thyratron to ground potential are shielded with a metal grid hose, carrying the return current, and are coiled around a ferrite ring with cross section A in N windings. The assembly is designed that the integrated voltage drop across the coil during the kicker pulse increases the magnetic flux density in the ferrite rings from negative to positive saturation: $\int V dt = NA \int dB = NA(B_{END} - B_{START})$. Thus posing a large resistance to the pulse current. [6]. The ferrite is biased with a negative magnetic field to achieve the largest effect and potted to improve its high voltage capability.

IV. PERFORMANCE

A prototype of the injection kicker pulser has been intensively tested and optimized in 1989. Work was done in particular to optimize the shielding of the RF noise and to improve the high voltage capability of the compact pulser enclosure. Fig. 4 gives the form of the current pulse as sensed

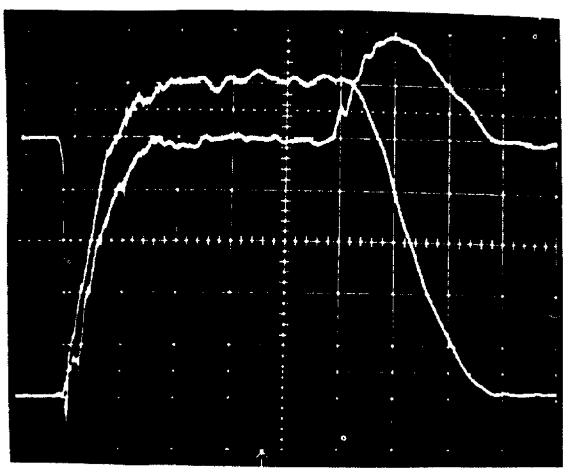

Figure 4
Current and $d\phi/dt$ Pulse of the Injection Kicker

with a current transformer. The scale is 100 nsec/div and 100 A/div for the horizontal and vertical axis, respectively. The pulse height of 600 A corresponds to about 15 kV PFN voltage. The pulse has been produced by 100 m long PFN cables. The separation of the cathode voltage from ground works very well. The injection kicker has routinely been operated since the beginning of the booster commissioning in July 1990. Routine operation of the ejection kicker started in October 1990. The performance of the kickers is very satisfying. The injection efficiency into the booster often exceeds 80 to 90 %. With optimal settings of the booster correctors the intensity doesn't drop significantly in the first revolution. This indicates that kicks caused by the reflected pulse current are small enough to keep the injected beam within the vacuum aperture. The electromagnetic noise generated by the kickers during the pulse reduces the sensitivity of the transport line beam position monitors that are located closely to the kickers. Fig. 4 also shows the $d\phi/dt$ signal measured with a one loop coil in the gap of the kicker magnet. Fig. 5 shows the gap field vs. time (i.e. the integrated $d\phi/dt$, normalized to the coil area).

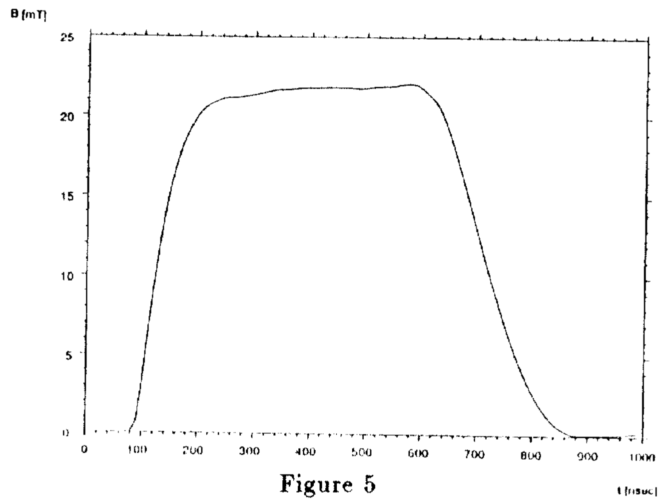

Figure 5
Magnetic Field Measurement in the Gap of the Injection Kicker

V. ACKNOWLEDGEMENTS

A study by A. Fisher [7] comparing different kicker-magnet circuits aided the design of the pulse generator. We wish to thank R. Cassel from *SLAC* for his consulting aid during the design and development phase of the pulse generator and may of the *SSRL* staff members for their support.

VI. REFERENCES

[1] J. Safranek and S. Baird, "Commissioning the SSRL Injector." In these proceedings, 1991.

[2] R. Hettel, R. Averill, M. Baltay, S. Brennan, C. Harris, M. Horton, C. Jach, J. Sebek, and J. Voss, "The 10 Hz Resonant Magnet Power Supply System for the SSRL 3 GeV Injector." In these proceedings, 1991.

[3] M. Borland, J. Weaver, M. Baltay, L. Emery, R. Hettel, H. Morales, J. Sebek, B. Youngman, R. Anderson, A. Fisher, and R. Miller, "Design and Performance of the Traveling-Wave Beam Chopper for the SSRL Injector." In these proceedings, 1991.

[4] R. Hettel, D. Mostowfi, R. Ortiz, and J. Sebek, "Triggers and Timing System for the SSRL 3 GeV Injector." In these proceedings, 1991.

[5] G. Gabor and F. Voelker, "Kicker Magnets for the Advanced Light Source," in *Proceedings of the 1989 Particle Accelerator Conference, Chicago*, March 1989. IEEE Catalog Number 89CH2669-0.

[6] R. Cassel, "private communication," 1989.

[7] A. Fisher, "Comparison of Kicker-Magnet Circuits," ACD-Note 71, SSRL, 1989.