OPERATING CHARACTERISTICS OF THE PLS INJECTION KICKER MODULATOR

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Abstract

An injection kicker modulator of the Pohang Light Source (PLS) drives four kicker magnets simultaneously. With assistant of kicker magnet field, the injected electron beam falls into the storage ring (SR) beam dynamic aperture. The kicker modulator was upgraded and installed in August 1995. Since then, the kicker modulator has shown very reliable and stable performance. The kicker modulator specifications are ~6.0 µs full width, ~24 kA peak current, and 10 Hz repetition rate. Output current waveform is a half sinusoid. Two thyratron switches (EEV CX-1536AX) are used in the kicker modulator. Total accumulated thyratron heater run time is about 14,000 hours as of February 1998. Measurement result of spatial magnetic field distribution in the kicker magnet shows good uniformity.

1 INTRODUCTION

The Pohang Light Source (PLS) is a third-generation synchrotron radiation facility. The 2 GeV full energy electron beam from the linac is transported through a beam transfer line (BTL) to the storage ring. The injected beam from the BTL line into the storage ring is placed within the storage ring beam dynamic aperture by kicker magnets. A total of four kicker magnets are used to disturb the normal storage ring beam orbit toward the septum magnet wall. Only one kicker magnet modulator is used to drive the four kicker magnets, to give balanced current for all four magnets and to have precise timing between magnet currents. A desirable current pulse shape is a half sinusoid.

2 INJECTION KICKER MODULATOR

2.1 Structure of Injection Kicker Modulator

A schematic circuit diagram of the kicker modulator is shown in figure 1 [1]. The injection kicker modulator is series resonant circuit. Specifications of the kicker modulator are given in Table 1. Output current waveform is a half sinusoid. Thyratron switches in the figure 1 should then block negative current. Due to the characteristic of a resonant circuit, a high inverse voltage is naturally produced during the negative current blocking. The inverse voltage can become as high as the charging voltage. However, the full inverse voltage of 16kV can not be handled by the thyratrons. Moreover,

Table1: Specifications of the kicker modulator

Parameter	Specification
Peak Current:	24.06 kA
Pulse-Width:	6.0 µs
FWHM:	4.0 µs
Flat-top Width (< ±0.2%):	200 ns
Repetition Rate:	10 Hz
Peak Charging Voltage:	16.5 kV
Total System Inductance:	1.17 µH
•Total Load Inductance:	0.867 µH
•Total Stray Inductance:	0.303 µH
Total System Capacitance:	3.2 µF
Energy per Pulse:	435.6 Joule
Maximum Operable Beam Energy:	2.0 GeV

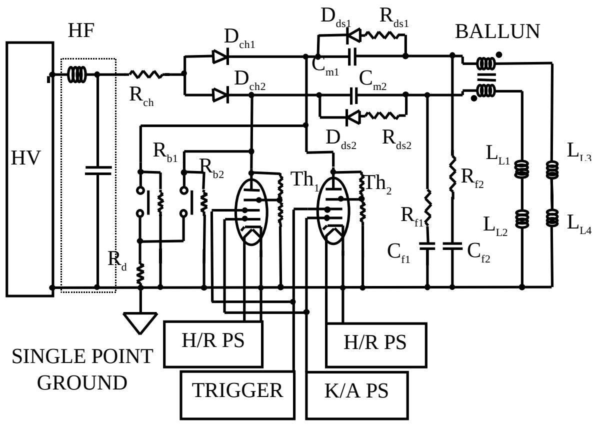

Figure 1: Schematic Circuit Diagram of Kicker Magnet Modulator.
- HV: High Voltage DC Power Supply (30 kV, 8kJ/s)
- C_{m1}, C_{m2}: Main Capacitor (1.6µF, 30kV, 80% reversal each)
- L_{L1}, L_{L2}, L_{L3}, L_{L4}: Kicker Magnet (0.867 µH each)
- HF: High Frequency Filter
- R_{ch}: Charging Resistor (60 Ω)
- R_{b1}, R_{b2}: Bleeding Resistor (20 MΩ each)
- D_{ch1}, D_{ch2}: Charging Diode
- R_{ds1}, R_{ds2}: Discharge Resistor (2 Ω each)
- D_{ds1}, D_{ds2}: Discharge Diode
- R_{f1}, R_{f2}: Surge Suppression Resistor (5 Ω each)
- Th_1, Th_2: EEV CX1536AX Thyratron
- C_{f1}, C_{f2}: Surge Suppression Capacitor (178 nF each)
- R_d: Dump Resistor (5 kΩ)

the lifetime of capacitors strongly depends on the inverse voltage. Thus, the reduction of the inverse voltage is very important in a resonance circuit. The inverse voltage reduction is realized here by adopting transient suppression assemblies (R_{f1} and C_{f1}, R_{f2} and C_{f2} in Figure 1) and also inverse energy dump assemblies (D_{ds1} and R_{ds1}, D_{ds2} and R_{ds2} in Figure 1). The inverse energy dump assemblies are in parallel connection with main capacitors. Role of the inverse dump assembly is to discharge inversely charged voltage on capacitors while maintaining the forward charging energy. The transient suppression assemblies are connected in parallel with the magnet loads in order to maintain a continuity of the load current after a discharge cycle. By maintaining the load current, abrupt inverse voltage development across thyratrons and capacitors are minimized. A microprocessor-based circuit manages control and communication of the kicker modulator. A standard IEEE 422 bus is used for the communication. A high voltage power supply and the machine control system are positioned at a SR RF station room where operators can gain access freely during the beam operation. Others are positioned at the SR tunnel near the magnet load so that unnecessary stray component can be minimized. The thyratrons used here is EEV CX1536A. They can handle 10 kA peak current and 250 MW peak power. As given in the table 1, the required full load current at a 2 GeV operation is 24.06 kA. Since two thyratrons are used, the peak anode current required for each thyratron is 12.03 kA. Therefore, we are driving thyratrons with higher current than their peak rating.

2.2 Performance of Injection Kicker Modulator

The measured load current is shown in the Figure 2. The Peak current is 22.8 kA. The peak negative swing current is 2.2 kA at ~7 µs. The full pulse-width is 6.32 µs. The circuit load current waveform is not symmetric and has negative swing. The negative swing appears due to the RC transient suppression assemblies. Voltage across a thyratron is measured and presented in figure 3, which shows the thyratron anode voltage during 10 Hz operation. The charging voltage is 16 kV. In this figure, the thyratron inverse voltage can clearly be recognized. Less than 10 kV thyratron inverse voltage is achieved with 16 kV charging. The maximum permissible inverse voltage is 10 kV is for the thyratrons.

The injection kicker modulator was installed on August 1995. Thyratron heater running time was 2,500 hours in 1995, 5,100 hours in 1996, and 6,100 hours in 1997. Total accumulated operation time is 14,000 hours as of February 1998. Since the installation of kicker modulator, several faults have been recorded. However, we have not faced any major faults, such as thyratron, main capacitor, and HVPS failures. Most of the failures were due to strong switching noise that affected communication, control, and interlock circuits. This type of faults did not seriously delay overall injection time since it only required simple reset action to recover. Two thyratron trigger generator failures have been observed. The trigger generator failure required replacement of semiconductor switching devices (IGBT). It generally took about three hours to replace IGBTs in the trigger generator. Overall performance of the injection kicker modulator has been very stable and reliable. Normal operating condition of the kicker modulator is given in Table 2. In this table, only parameters that differ from those on Table 1 are listed. With the peak output current given in Table 2, 2.0 GeV beam is bumped about 14 mm or 11.11 mrad.

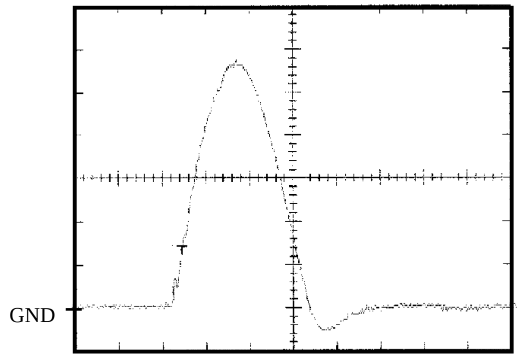

Figure 2: Measured load current (16 kV charging) (2 V/Div., 2 µs/Div.). 2kA/V, 22.8 kA peak, 6.32 µs pulse-width, 4.08 µs FWHM.

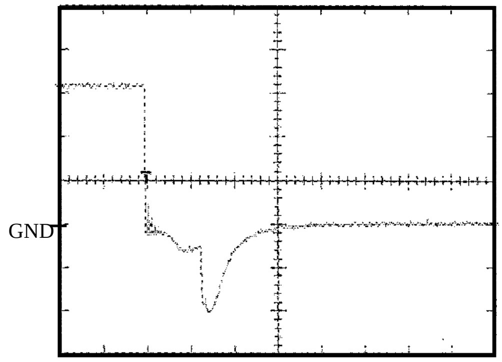

Figure 3: Thyratron anode voltage (16 kV charging) (5V/Div., 2µs/Div.). 1kV/V, 16kV peak

Table 2: Normal operating condition of injection kicker modulator.

Parameter	Operating value
Charging voltage [kV]:	11 to 12
Peak output current [kA]:	16 to 18
Thyratron No. 1:	
Heater Voltage [V]:	6.23
Heater Current [A]:	88.5
Reservoir Voltage [V]:	6.3
Reservoir Current [A]:	7.2
Thyratron No. 2:	
Heater Voltage [V]:	6.22
Heater Current [A]:	90.6
Reservoir Voltage [V]:	6.3
Reservoir Current [A]:	7.13

3 KICKER MAGNET

Major parameters of the kicker magnet are listed in Table 3 [2]. Kicker magnet characteristics are studied to find field distribution and maximum operable peak current of the magnet. Figure 4 shows structure of kicker magnet core. The core material is MN-80C ferrite. Magnetic field reference axes are also shown in the figure. A B-dot probe and integrator assembly is used to measure the magnetic field. Results of the measured magnetic field along the x and z axes show that the field distribution is fairly constant throughout the magnet. Figure 5 shows an example of z-axis field distribution. In Figure 6, a variation of peak magnetic flux density is plotted as the applied magnet current increases. As shown in the figure, the magnet starts to saturate around 12 kA (point A). Saturated waveform that is measured at the point B in Figure 6 is shown in Figure 7. From the figure, one can recognize that B-field becomes flat at the peak. This implies that the magnet is saturated. From this measurement, we conclude that the present kicker magnet can operate up to 12 kA. This maximum operable current allows 21 mm or 16.67 mrad bump at 2 GeV. The 21 mm bump is the required maximum bump distance at 2.0 GeV. To inject higher energy beam than 2.0 GeV, the kicker magnet needs to be replaced with a larger size one.

Table 3: Specification of kicker magnet.

Parameter	Specification
Beam Energy	2.0 GeV
Bending Field	0.1324 T
Maximum Relative Field Deviation	± 0.5 %
Max. Time Jitter between Magnets	6 ns
Number of Turns per Pole	1 turn
Resistance of Magnet @40 ℃	8.28 mΩ
Inductance of Magnet	0.867 μH
Gap Height	0.04 m
Gap Width	0.11 m
Magnet Length	0.5998 m

4 CONCULSION

An injection kicker modulator of PLS was upgraded and installed on August 1995. The kicker modulator drives four kicker magnets to deflect injected electron beam from the PLS beam transfer line. Total accumulated operation time is over 14,000 hours as of February 1998. During the operation period, the kicker modulator has not given any major failure and has been very stable and reliable. Measurements of internal magnetic field in the kicker magnet show a uniform spatial distribution. Maximum operable current per a kicker magnet before saturation is measured to be 12 kA. The maximum current allows 21 mm or 16.67mrad bump at 2 GeV injected electron beam energy.

5 REFERENCES

[1] S. H. Nam, S. H. Jeong, S. H. Han, J. H. Suh, and K. M. Ha, " Kicker magnet modulator in 2 GeV Pohang Light Source," 4th Int. Conf. on Synchrotron Radiation Sources, Kyungju, Korea, Oct. 1995.

[2] John Milburn and Namsoo Shin, "Injection system parameter list," PAL Engineering Note IN-007, July 1992.

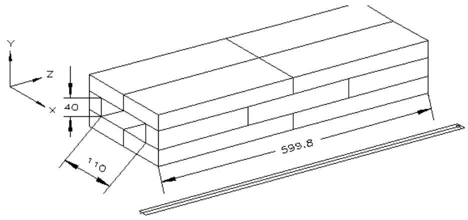

Figure 4: Structure of kicker magnet core.

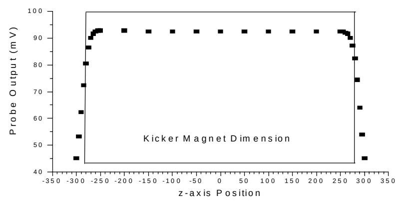

Figure 5: Z-direction spatial field distribution in kicker magnet.

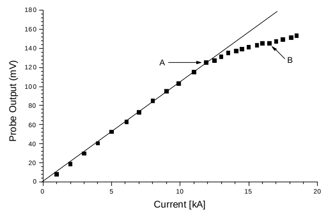

Figure 6: Peak current versus peak magnetic flux density in the kicker magnet.

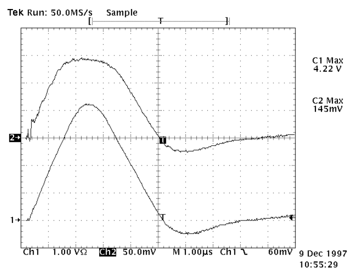

Figure 7: Waveforms of current(bottom: I=16.4 kA) and magnetic flux density(top) at point B in Fig 6.