

PULSE POWER SUPPLIES FOR THE DIPOLE KICKERS OF MAX-IV AND SOLARIS STORAGE RINGS*

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Abstract

For initial operation of the MAX-IV and Solaris storage rings the single dipole kickers were decided to use. The pulsers which drive the magnets have the following requirements: current amplitude up to 4kA (3 GeV ring), pulse length 0.6 μ s (1.5 GeV ring) and 3.5 μ s (3 GeV ring), pulse amplitude stability $\pm 0.1\%$, timing jitter $< \pm 5$ ns, maximum repetition frequency 10 Hz. The design and test results of the pulse power supplies are presented in the paper.

INTRODUCTION

The MAX IV facility presently under construction will include two storage rings for the production of synchrotron radiation: the 3 GeV and 1.5 GeV storage rings [1]. Both rings will be operated with top-up shots supplied by the 3.5 GeV MAX IV linac acting as a full-energy injector at up to 10 Hz repetition rate. At the commissioning phase the single dipole kickers will be used for the injection in the both rings. In addition pulsed vertical kickers (pingers) are needed for performing tests with the stored electron beam. The copy of 1.5 GeV ring is built for Solaris light source in Poland. The paper describes the design and tests of power supplies for these magnets.

Table 1: Pulse Magnet Systems Specifications

	1.5GeV		3GeV	
	kicker	pinger	kicker	pinger
Magnet inductance, nH	2x480	130	615	235
Integrated field, Gm	143	75	450	110
Peak current, A	1060	2050	3600	2600
Pulse length, μ s	0.64	0.64	3.5	3.5
Maximum rep. rate, Hz	10	1	10	1
Pulse to pulse repeatability, %	± 0.1	± 1	± 0.1	± 1
Pulser to magnet feedline length, m	13	13	15	14

The requirements for the pulse magnet systems are listed in the table 1. The reverse spike (undershoot) after the pulse shall have an amplitude of less than 10% of the pulse amplitude and last less than 0.2 μ s (1.5 μ s for 3 GeV ring magnets), after which the residual amplitude shall be smaller than 0.1% of the peak amplitude. Pulse-to-pulse timing jitter and drift must be less than ± 5 ns for all magnets.

POWER SUPPLY DESIGN

For production simplicity the design of all power supplies is chosen similar. The power supply consists of pulser unit, charging power supply and control electronics crate located in a single power supply rack (see Fig. 1). The magnet is connected to the pulser via transmission feedline made of 10 pieces of RG-213 cable. For matching the pulser circuit to the magnet an appropriate matching circuit is utilized. Parallel connection of the 1.5 GeV kicker magnet buses allows to decrease the charging voltage of the pulser at the expense of increasing of the switching peak current. The rest of magnets have conventional series connection of the buses.

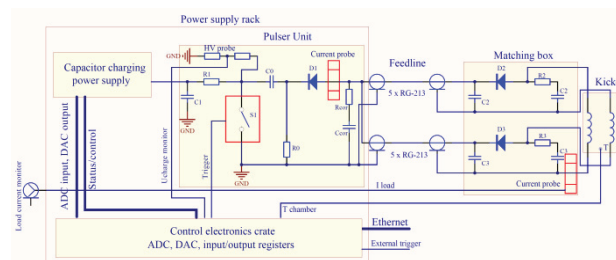


Figure 1: 1.5 GeV injection kicker power supply block diagram.

To generate the required current pulse in the inductive load a resonant discharge of capacitance through the transmission line to the load is utilized. In the case of short pulse power supplies (1.5 GeV ring magnets) the transmission line delay time is compared to the pulse rise time. The energy stored in this line is also rather high, so it is not possible to form the current without successive reverse pulse in the inductive load. Therefore clipping diodes (D2, D3) should be placed at the load side of the transmission line. SiC Schottky diodes C4D40120D with no reverse recovery charge are the constituents of the diodes D2/D3 and D1. For long pulse pulsers (3 GeV ring magnets) hyperfast soft recovery diodes RHRG75120 are used to clamp the reverse current (diode D1).

The main resonant capacitor of the pulser circuit (C0) consists of parallel/series connection of polypropylene film capacitors produced by WIMA. Capacitors (C0) and diodes (D1) are mounted on a single PC board. Short pulse pulsers have identical storage capacitors boards including 45 capacitors in 5 series groups and 15 diodes in 5 series groups. 3 GeV kicker pulser has two similar boards with total 160 capacitors and 48 diodes installed on them.

A switching unit S1 is assembled from parallel-series connected low voltage IGBTs. The simplified circuit is shown on Figure 2. Each transistor T1-TN represents parallel connection of 8-10 single IGBTs. Every section

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of the switch assembly has local IGBT driver with high pulse current capability. The driver power supply is provided by isolation transformer with a single turn primary and a set of ferrite cores with secondary windings located in each section. The triggering of the sections is also implemented by the isolation transformer with both primary and secondary windings made of single turn. DC sharing of the voltage across the transistors is assured by resistive divider R1-RN. Because of equal delays of the IGBT drivers and fast gate voltage rising (<60ns) the switching on of all sections occurs almost simultaneously. The switch operates as a closing element only and it is opened at zero current in the circuit. Therefore there is no requirement for the switch sections to turn off synchronously.

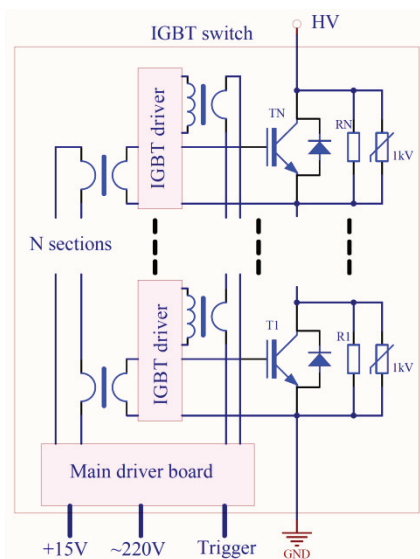


Figure 2: IGBT switch simplified circuit.

Short pulse pulser units has identical switch assemblies composed from 10 sections with 8 parallel IGBTs. Each IGBT is IRG7PH42UD transistor rated at 1200V and 45A average current. The assemblies for 3 GeV ring pulse systems consists of 10 IRG7PSHUD transistors sections. 3 GeV kicker pulser contains 7 sections and 3 GeV pinger – 4 section in series. The maximum tested switching current rise rate was about 15 kA/μs for the assembly.

The high voltage charging power supply is CCR series power supply produced by Technix. 150 J/s charging rate power supplies are used for all power supplies except of 3 GeV kicker power supply which is equipped with 600 J/s unit. For reducing the charging voltage ripples 1.2 μF filter capacitor (C1 on Figure 1) is installed in the kicker’s pulser units.

The power supply control system is based on LCARD control crate LTR-EU-16-1 with embedded controller. It carries a set of electronic modules (DAC, ADC, input and output registers) and provides Ethernet interface to the external control system. Additional specially designed module provides interlock signals handling and control functions.

All units of the power supply are assembled in the 19” 25U height rack. 10 Hz repetition rate systems have forced ventilation of the pulser unit. The specifications of the main components of the power supplies are summarized in the table 2.

Table 2: Power Supply Components Specifications

	1.5GeV		3GeV	
	kicker	pinger	kicker	pinger
Main storage capacitance (C0), nF	39.6	39.6	640	715
Nominal charging voltage, kV	7.4	7.6	5.8	3.05
Switch peak current, kA	1.24	1.3	3.55	2.6
Number of sections in the main switch	10	10	7	4

TEST RESULTS

Presently all pulse magnet systems are assembled. The test results of 1.5 GeV kicker and 3 GeV kicker pulse systems are presented below.

Magnetic Field and Current Waveform Test

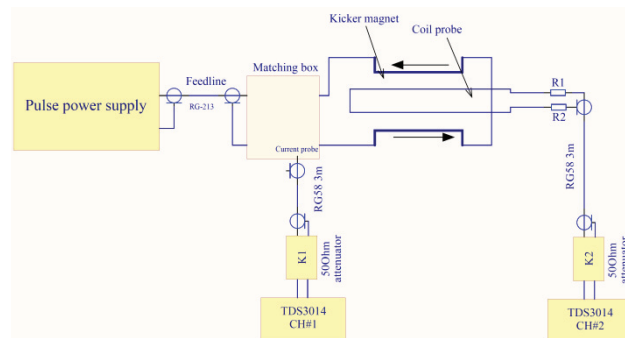


Figure 3: Magnetic field and current waveform measurement test stand block diagram.

The waveform test was performed at the test stand which block diagram is shown on Figure 3. Magnetic field waveform is measured by single turn coil probe manufactured on a pc board. The current is measured by Magnelab CT-C0.25 current transformer.

All waveforms below are the result of averaging over 512 shots. The waveform digitized by CH#2 of the scope is integrated numerically. Because of electric field peak up to the coil probe from the magnets high voltage buses the averaging between two experiments are implemented to compensate for this error: $B_{result} = (|B_+| + |B_-|) / 2$.

Where $|B_+|, |B_-|$ - the B-field waveforms resulted from two opposite orientations of the coil.

Figures 4,5 show the waveforms obtained at nominal output current for 1.5 GeV kicker and 3 GeV kicker magnets. All waveforms are normalized to their peak values. The B-field waveform plotted on Figure 5 is

obtained without rotating the coil. Therefore some distortion caused by electric peak up is presented on the graph.

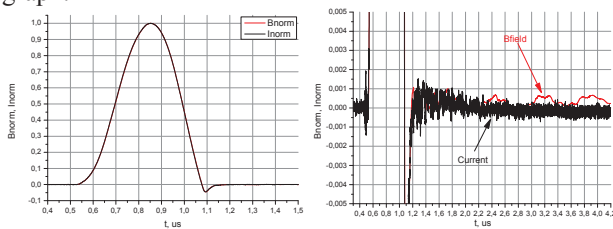


Figure 4: B-field and current waveforms of the 1.5 GeV kicker at nominal output current.

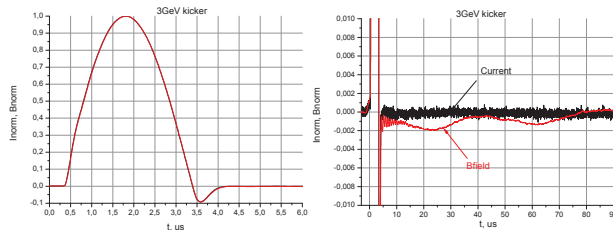


Figure 5: B-field and current waveforms of the 3 GeV kicker at nominal output current.

Heat Run and Repeatability Test

Peak charging voltage U_{charge} and peak magnet current I_{magnet} were measured during the test. The charging voltage was measured by LTR-114 ADC (a constituent of the control electronics crate). The signal of magnet current is digitized by Lecroy WaveSurfer 44xS oscilloscope. Moving average filter is applied to the signal (the effective bandwidth is reduced to 20MHz) for effective noise reduction. Also the whole signal is shifted, the top of the pulse is magnified that increases the amplitude measurement precision.

Total running time during tests for each system was about 10^6 pulses. No degradation of pulse shape and amplitude was observed.

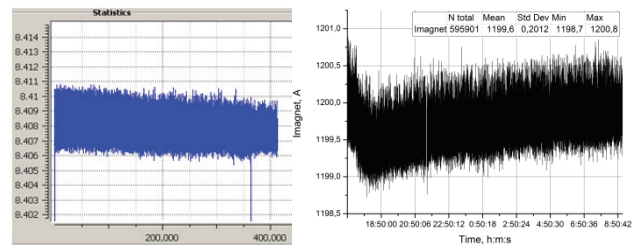


Figure 6: 1.5 GeV kicker running at 10Hz rep. rate 8.4kV (113% of nominal current).

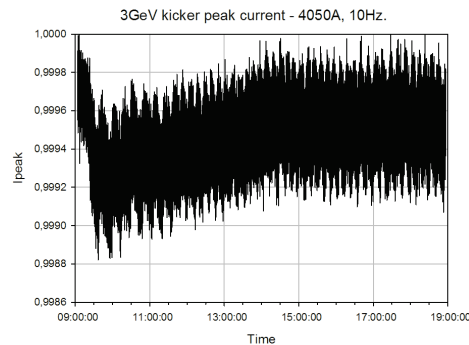


Figure 7: 3 GeV kicker running at 10Hz rep. rate 6.4kV (113% of nominal current).

CONCLUSION

A number of pulse power supplies with IGBT-based switch were manufactured. Good stability and reliability of the systems were confirmed by long term testing of two pulse magnet systems.

REFERENCES

- [1] S. C. Leemann, A. Andersson, M. Eriksson, L.-J. Lindgren, E. Wallén, J. Bengtsson, and A. Streun, Phys. Rev. ST Accel. Beams 12, 120701 (2009).