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FAST INJECTION SYSTEM R&D FOR THE APS UPGRADE*

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Abstract

The MBA upgrade for the APS will operate with bunch swap out and vertical on-axis injection. The planned 324 bunch fill pattern places difficult demands on the injection and extraction kickers. The present concept uses dual stripline kickers driven by high voltage (HV) pulsers. Minimizing perturbation on adjacent bunches requires very fast rise and fall times with relatively narrow (< 20 ns), 15 kV pulses. To achieve these requirements, a multifaceted R&D program has been initiated. The R&D includes the HV pulser, stripline kicker and HV feedthrough. The requirements for injection and extraction, progress on prototype development, and results of our HV pulser investigations are discussed.

INTRODUCTION

The Advanced Photon Source (APS) storage ring will be upgraded to use a multiband achromat (MBA) lattice to provide enhanced hard x-ray brightness and coherent flux to beam-lines [1]. The MBA lattice will operate with bunch swap out and vertical on-axis injection. In this scheme, a target bunch will be extracted to a beam dump and the resulting empty RF bucket filled with a replacement bunch from the APS injectors. The planned 324 bunch fill pattern with its 11.4 nanosecond bunch spacing places very demanding requirements on the extraction and injection systems to minimize perturbations to the stored bunches immediately upstream and downstream of the target bunch. The extraction and injection sections will each consist of four dual blade small-aperture stripline kickers with each kicker driven by a fast dual output high voltage pulser. In addition, the injection section will include a Lambertson septum. Parameters for the injection/extraction sections are listed in Table 1.

To address these requirements, an R&D program is underway which includes the kickers, fast high voltage pulsers and high voltage feedthroughs.

KICKER

Swap-out injection will require pulsed deflecting kickers fast enough to select individual bunches spaced as closely as 11.4 ns without significantly disturbing neighboring bunches.

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Table 1: Injection/Extraction Parameters

Key Parameters		
Total Kick Angle	2.88	mrad
Number of Kickers	4	
Kicker Strength	1	mrad/m
Length of Each Kicker	72	cm
Blade to Blade Voltage	30	kV
Vertical Aperture	9	mm
Minimum Bunch Spacing	11.4	ns
Maximum Residual kick to Stored Beam	< 2.5	% amplitude
Pulse Rise Time (10%-90%)	4.5	ns
Pulse Width (90%-90%)	5.9	ns
Pulse Fall Time (90%-10%)	4.5	ns

Physics

Impedance-matching plays an essential role in achieving maximum kicker strength, reducing local high voltage concentration, which can lead to breakdown, and minimizing beam impedances. The optimization strategy is to match the differential impedance as close as possible to a 50 ohm line impedance, while allowing some mismatch in the common mode impedance [2]. A "vaned" body geometry has been adopted to provide better common mode impedance matching, while "D" shaped blades are used to improve field uniformity within the good field region. Figure 1 shows the cross section of the kicker.

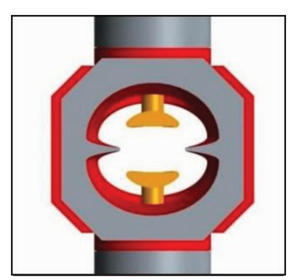

Figure 1: Kicker cross section.

The kicker has tapered end sections to better match the impedance to the feedthroughs. The design has been optimized by running a multi-objective optimization process with a 2D simulation program. A 3D simulation

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was then done on the optimized geometry. The 3D simulation provided further verification of the differential and common-mode impedance, field quality, the matching of the tapered body section of the kicker, and the interface to the feedthroughs. The optimized geometry gives a differential impedance of 49.6 ohms with a common mode impedance of 63.1 ohms.

Mechanical

The mechanical design of the stripline kicker is driven not only by the physics requirements, but also by available manufacturing technology and machine capacity to produce the required geometries. The kicker mechanical design consists of the body, two tapered transitions and two end caps. The D-shaped blades are 72 cm long and taper over the last 5 cm at both ends. They are supported only at the ends by the feedthroughs. All kicker parts will be machined from 316-L stainless steel using the wire electrical discharge machining (EDM) process. In addition, the interior finish of the kicker will be electro polished. The kicker body parts will be assembled and brazed in a vacuum atmosphere using a copper/gold braze alloy

Two prototypes of kicker assemblies will be fabricated, one with a one-piece body and the other with a two-piece body. The parts of the two-piece body can be manufactured to tighter tolerances than the longer one-piece body. However, the two-piece body can incur assembly errors in addition to small machining mismatches at the center assembly point. The two kicker bodies will be evaluated for achieved tolerances and the best one will be selected for further testing.

HIGH VOLTAGE PULSER

A total of eight dual output, fast, high voltage pulsers are required for the extraction and injection sections. Specifications for the pulser are listed in Table 2. The combination of high, required peak voltage and nanosecond scale rise and fall times place the pulser requirements at state-of-the art levels, and technology options are therefore limited.

The pulser R&D program consists of investigating different technologies to arrive at a reliable configuration. Presently two technologies are under consideration. The first is based on the use of nonlinear transmission lines (shock wave transmission lines (SWTL)) [3,4] to sharpen the edges of pulses produced by a thyratron pump circuit. APS has considerable experience with thyratron based pulsers at APS, but the native rise and fall times cannot meet the requirements for bunch swap-out operation. The second technology under investigation is a commercial high voltage pulser produced by FID [5].

A collaboration has been entered into with SLAC to investigate the suitability of the SWTL concept for the APS Upgrade. Figure 2 shows the concept for the SWTL assisted high voltage pulser.

Table 2: High Voltage Pulser Parameters

Parameter	Value	Unit
Maximum Output Voltage per Channel	20	kV
Dual Outputs	+/-	
Maximum Rise Time (10-90%)	4.5	ns
Maximum Fall Time (90-10%)	4.5	ns
Flat Top Width (at 90%)	5.9	ns
Maximum Pulse Tail Amplitude	2.5	%
Amplitude Stability	1	%
Maximum Time Jitter Between Channels	0.1	ns rms
Maximum Output Time Jitter to External Trigger	0.1	ns rms
Maximum Skew Between Channels	0.1	ns rms
Maximum Pulse Rate	10	Hz

This topology allows formation of high voltage pulses with a nanosecond rise time from slower rise time input pulses. The SWTLs are ferrite-loaded coaxial transmission lines. The concept consists of two pieces of coaxial transmission lines (SWL1 and SWL2) loaded with ferromagnetic cores. The rise and fall times of the pulse are formed by shock electromagnetic waves. SWL1 and SWL2 are charged in parallel. The SWL1 line is shorted on the end. One end of the SWL2 line connects to a 50 Ohm regular coaxial cable and drives the load. The formation of shock electromagnetic waves in SWL1 and SWL2 is realized by charging these line via a pulse circuit that is triggered from a synchronizing system. The SWL2 line forms the front edge of the pulse and the SWL1 forms the falling edge of the pulse. The pulse duration is set by the length of SWL1. A thyratron or arrays of solid state switches can be used charge the lines.

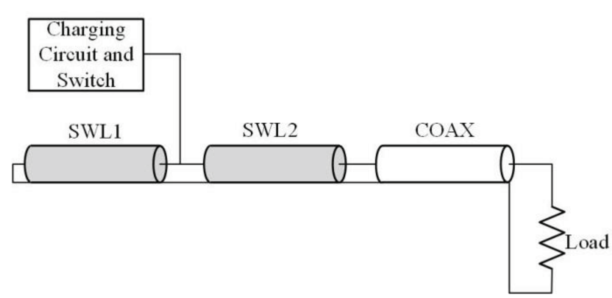

Figure 2: Shockwave transmission line assisted pulser.

SLAC has constructed and tested SWTLs, and has produced sharpened high voltage pulses with sub 5 nanosecond rise and fall times when driven by a thyratron based charging circuit. To assess the output voltage tuning range of the SWTL concept, pulse edge time, propagation delay, jitter, output amplitude, and output

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amplitude stability were characterized by varying the input charging voltage in 1 kV steps from 10 kV to 20 kV. The results showed that the propagation delay and edge times vary with the output (charging) voltage. The edge time changed from 5.4 ns to 4.5 ns when the charging voltage was varied from 12 to 18 kV, while the propagation delay changed by 16 ns as the charging voltage was changed from 12 to 20 kV. A more troubling issue was that considerable residual energy remained on the line after pulse completion. This residual energy appears to be difficult to eliminate without a more complicated circuit.

A dual output 20 kV high voltage pulser from FID [5] has been procured to use in testing the prototype kicker and also to evaluate reliability. The pulser was run continuously for nearly 17 weeks with 10 of those weeks run at +/- 20 kV output and 10 Hz repetition rate. Over the testing period, the pulser produced a total of 83M pulses with 68.5M of those pulses at +/- 20 kV. The 68.5M pulses at 10 Hz is equivalent to running the MBA swap-out injection continuously for ~10.9 years at a 5 second bunch swap-out interval. This performance was quite remarkable until the pulser failed in early March. It was sent back to the manufacturer for repair. A failed capacitor was replaced with what the manufacturer characterized as a more robust unit. The unit was quickly repaired and returned.

A second high voltage pulser with positive and negative 30 kV outputs has been procured from the same vendor and is undergoing testing.

HIGH VOLTAGE FEEDTHROUGH

The fast high voltage pulser rise and fall times require an rf type feedthrough that maintains a 50 Ohm impedance match throughout the structure. The HV feedthrough specification are listed in Table 3. No suitable off-the-shelf unit has been identified that can meet the ultrahigh vacuum and radiation resistance requirements for a kicker high voltage feedthrough. Negotiations are underway with a manufacturer [6] to develop a high voltage feedthrough to meet our requirements. The design uses multiple dielectrics to achieve the required impedance match throughout the structure.

TESTING

The fully assembled prototype kicker will be tested under vacuum on the bench where the RF properties will be evaluated.

After bench testing, the prototype kicker will be installed in the booster BTX line, which is a dump line off the APS booster to storage-ring transfer line. The kicker will be tested with 7 GeV beam from the booster. A downstream bpm and screen will be used to quantify the deflection achieved with the prototype. Testing should occur during summer of 2016.

Table 3: High Voltage Feedthrough Specifications

Parameter	Value	Unit
Maximum Voltage	>= 25	kV
Impedance	50 +/- 0.5	Ohms
RF Bandwidth	>= 1	GHz
Peak Current at Pulse Width of 30 ns	500	A
Maximum Pulse Width	30	ns
Maximum Pulse Rate	2	Hz

CONCLUSION

APS has initiated an R&D program for the injection/extraction systems required for the MBA upgrade. The program includes the kicker physics, mechanical design, high voltage feedthrough, and high voltage pulser.

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