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R&D AT SLAC ON NANOSECOND RANGE MULTI MW SYSTEMS FOR ADVANCED FEL FACILITIES*

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Abstract

A nanosecond range, multi MW system containing TEM mode electrodynamic structures fed by controllable pulsers are needed for (1) an array of FEL beamlines powered by superconducting linear accelerators operating with close MHz bunch repetition rate and (2) fast injection systems in multi-bend achromat upgraded (MBA-U) storage rings. The R&D effort covers both: type (1) and (2) layouts.

INTRODUCTION

L-Band CW linacs with approximately MHz bunch trains powered by a photoinjector are a fundamental to next generation FELs [1]. Such FEL projects require MW peak power spreader kicker systems of a nanosecond range. These systems have to distribute GeV bunches from the superconducting CW linac into beamlines with independently configurable undulators. In the ideal case, such systems allow the option to pick out bunches with arbitrary time pattern from a MHz bunch train. This technology optimizes the flexibility of the FEL for end users.

US Storage Ring Upgrades [2] are another example where nanosecond range multi-MW peak pulsers are required. They are necessary for the injection/extraction system to swap "bad" bunches with the new ones without shaking up the neighbours. Similar requirements were specified for the injection/extraction system of the ILC damping rings [3]. A main difference between [2] and [3] pulser specification is repetition rates. The repetition rate to swap bunches in the storage ring is approximately four orders of a magnitude lower compared to the ILC damping rings pulser.

The MaRIE complex [4] with pRad, XFEL, and eRad beamlines and switchyards is discussed presently. The electron bunch trains of the XFEL and eRad SC linacs will be unevenly spaced during 100 µs. The spacing between micro pulses is governed by the radiographic experiments. The unevenness in the bunch train formed in the photoinjector is a source of transients in the high Q accelerating structures. To avoid unwanted effects during accelerating mode, the MaRIE linac ends may contain a fast kicker system. The kicker system allows controlling the 12 GeV pulse train with the arbitrary bunch pattern. Pulses with fast rise/fall shapes are needed to knock out the unneeded bunches from the 100 µs train.

Discussed above are motivations for MW peak power systems of a nanosecond range in the feature. However, beamlines built now at SLAC LCLS-II XFEL may incorporate the pump-probe experiments with two bunches. A separation between bunches is approximately 10 ns. A fast kicker system is required to control the bunch destination. The beamline layout is illustrated in Fig. 1.

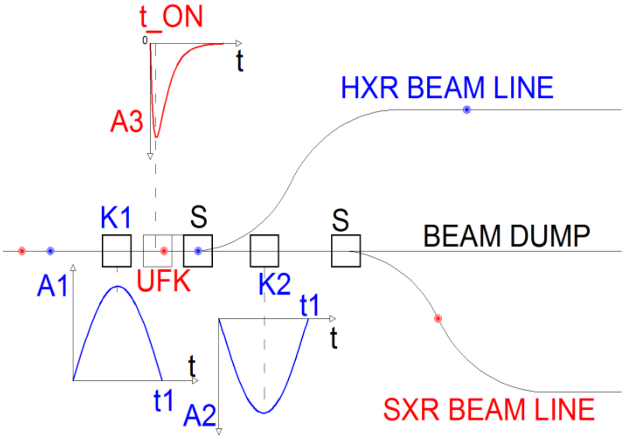

Figure 1: LCLS-II beamline scenario for pump-probe experiments. Red and blue dots represent two bunches, which propagate from the left to the right. K1 and K2 boxes are "slow" kicker magnets. Their transverse force (A1 and A2) vs. time (t) is shown in the blue curves. Two septum magnets (S) direct bunches into the hard or soft X-ray beamlines. The "fast" kicker system (UFK) is introduced into this beamline for the pump-probe experiments. The transverse force peak (A3) of the UFK vs. time (t) is shown in the red curve and cancels the kick K1. The system is activated when the separation between bunches is approximately 10 ns. The resulting x-rays, of different color, would be recombined for pump-probe experiments.

Figure 1 illustrates one possible scenario with a fast kick ON time (t_ON) and slow decay. The reader can find other scenarios with the fast kicker system in [5] where fast kick OFF time is discussed too.

GENERAL SPECIFICATIONS FOR FAST KICKER SYSTEM

Table 1 shows a general requirement for fast kicker system.

Table 1: Required Specifications

Parameter	Requirement	Unit
Deflection	0.75	mrad
Bunch Energy	4.0	GeV
Aperture	10	mm
Rise or/and Fall time	10.8 is good, 5.4 is better	ns
Repeatability	100	ppm rms
Availability	Low	
Pre-pulse/Post-	5	% of peak

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pulse		pulse
Residual field at the time of the next duplet	0.01 is good 0.02 I is manageable	G*m
Rate	10 (more is better 1 ok to start)	kHz

POTENTIAL ENGINEERING SOLUTIONS

A TEM mode kicker system is an attractive concept for advanced FEL facilities due to the ability to select individual bunches as needed. The electrodynamic kicker structure represents a broadband transmission line. The structure is very well studied and broadly used in the accelerator field. Our main R&D effort is focused on the pulser technology. Potential engineering solutions of multi- MW nanosecond pulsers were broadly discussed in the frame of R&D activities for the ILC damping rings ten years ago [6]. The 2006 Cornell Workshop in this regard selected: (1) inductive adder pulser concept (LNLL/SLAC), (2) pulsers based on Drift Step Recovery Diodes (SLAC), (3) commercial available pulsers from FID, Inc., (4) pulsers from Kentech, Inc., (5) pulsers from Behlke Inc. etc. All solutions are still valid for discussed advanced FEL facilities. An array of fast MOSFETs is used in (1). Several groups around world adopted this concept successfully. All needed components are available from industry. The FID, Inc. (and Megaimpulse) pulsers are effective solution from a cost and peak power point of view. However their technical solutions are based on proprietary technology. "Know-how" solutions are employed in their products. Several institutions successfully tested the FID pulsers for accelerator applications.

The R&D activity at SLAC adopts two well-known approaches to realize a multi-MW nanosecond peak power at resistive load. In both cases a non-linear media is used to assist a commercially available "slow" switch. The magnetic permeability of a ferromagnetic material and the conductance of semiconductors are common parameters that can be used to "speed up" a "slow" primary switch. A di/dt rate for all high-power switches (gas filled and solid state) shows that the current rise rate is reduced vs. switching current amplitude. It is known that the transmission line with ferromagnetic material may behave in an opposite way: a current rise rate on the output of a transmission line is an inversely proportional to the acting current amplitude. Such lines can assist the industry available switches to generate a high di/dt. Theory and engineering issues for a NTL design was developed in 60th [6].

Formation of solid state plasma and fast ionization processes in Si-base materials are the second approach where di/dt speed may be dramatically higher than takes place in the primary "slow" switch. A fast change of conductivity is limited by the saturated velocity of carrier in the solid-state semiconductor. For example, the saturated speed in Si-based semiconductor is approximately 10^{-2} cm/ns. So, the semiconductor thickness of 0.1 mm can change the conductivity during a 1 ns interval. Theory and engineering issues for this mode operation in semiconductors were developed in the 1980s [7]. The technology of DSRD fabrication was developed in the former USSR. The DSRD user community is not large and that is why there has not been a western supplier of similar devices in the past. This statement is not accurate for present-day, because the DSRD production capability has been transferred to the USA in the period from 2006 to 2013 under the SBIR DoE Phase I and II grant.

TABLE-TOP PULSE DEMONSTRATORS

Simplified circuit layouts for table-top demonstrators are shown in Fig. 2.

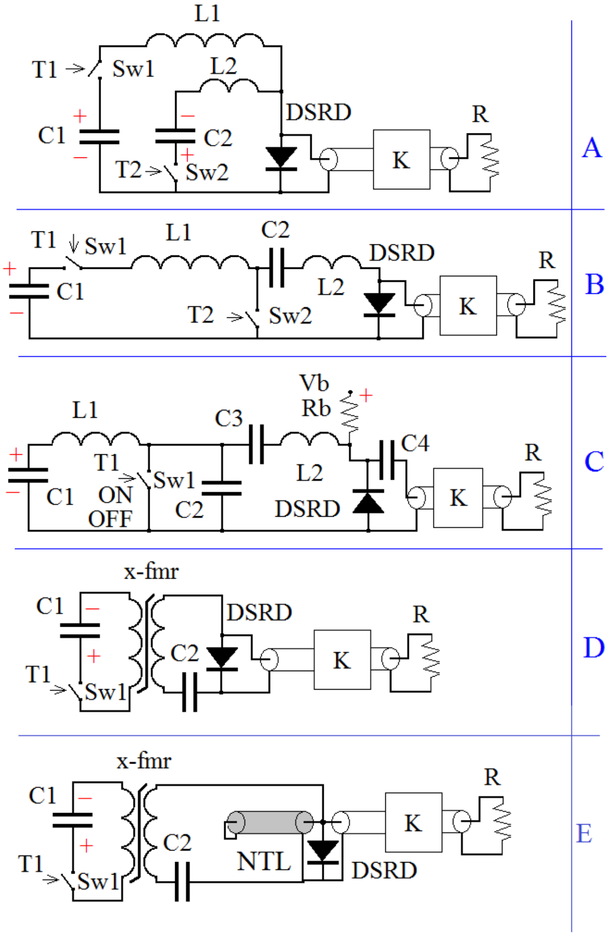

Figure 2: Simplified circuit diagrams for table-top demonstrators. Sw1 and Sw2 are primary "slow" switches governed by the external trigger (T1 and/or T2). DSRD and NTL are assisting "slow" switch.

The "A" and "B" layouts required two ON-type switches (Sw1 and Sw2) that are synchronized independently via T1 and T2. A DSRD is a two-terminal dynamic OFF switch that works with high current densities. The DSRD conductance is controlled by space charge effects in the p-n junction during pumping of semiconductor in forward

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and reverse directions. Amplitudes I_{FWD} and I_{RE} depend upon charging voltages, and circuit parameters. The "C" and "D" topologies employ only one primary switch (Sw1). However, the "C" topology uses the ON/OFF primary switch. The "D" circuit diagram is planning to be used for UFK pulser in LCLS-II for the pump-probe experiments. Figure 3 shows the pulser output waveform, and Fig. 4 shows the lab table-top Demonstrator #1 setup.

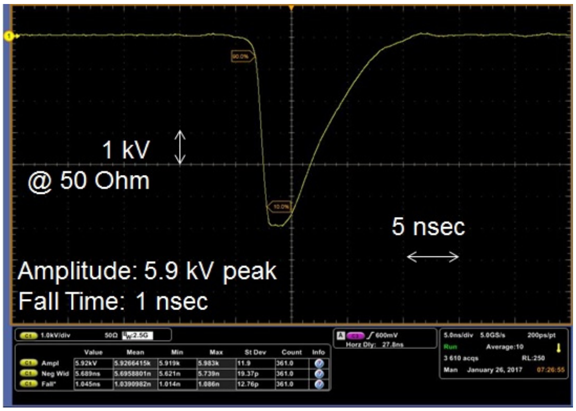

Figure 3: Output waveform with 1 ns fall time.

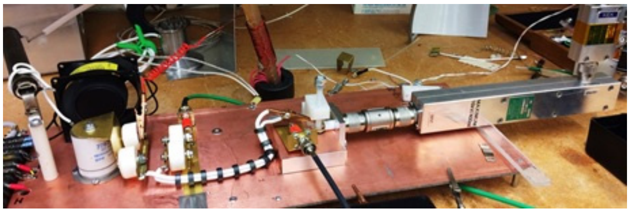

Figure 4: Lab table-top demonstrator #1.

The "E" circuit topology was used to demonstrate a multi-MW nanosecond pulse for the injection/extraction system. The output waveform is shown in Fig. 5.

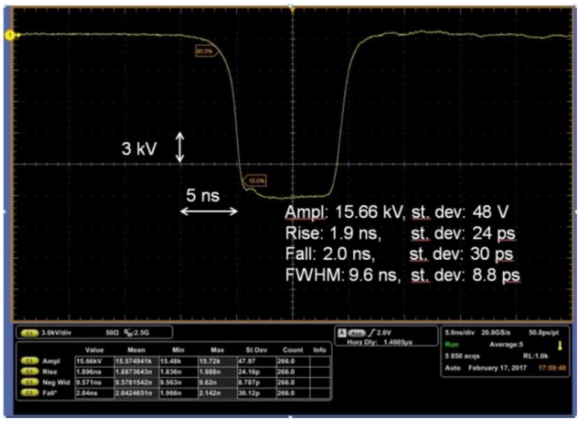

Figure 5: Output waveform with 2 ns rise and fall time.

In this case the HY-3189 thyratron was employed as a primary "slow" switch. A table-top Demonstrator #2 is shown in Fig. 6.

An evaluation of a field rigidity shows that Demonstrator #2 produces approximately 70+ G-m kick with a 100 cm TEM kicker structure. Advanced TEM kicker structure is shown in Fig. 7.

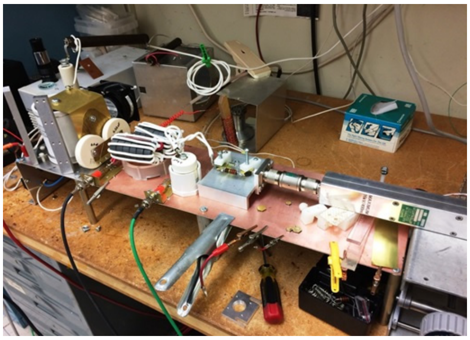

Figure 6: Lab table-top Demonstrator #2.

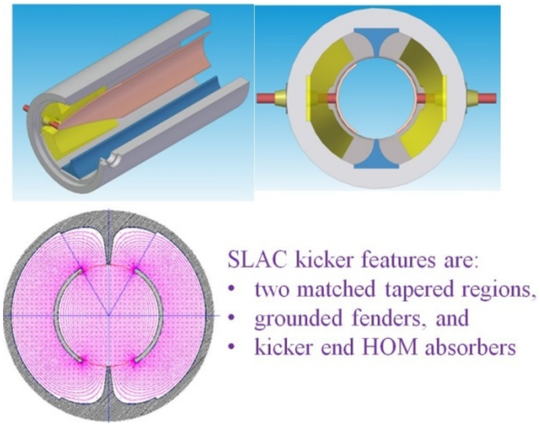

Figure 7: Proposed in the 2002 TEM kicker structure for ILC DR [8] may be used in the advanced FEL facilities.

CONCLUSION

Our R&D results show that the known pulser concepts based on the assistance of non-linear materials (ferromagnetic and semiconductor) are attractive, promising, and a cost-effective solution for employment in the advanced FEL installations. A particular application of immediate research is a kicker for LCLS-II which requires <10 ns transit times such that two electron bunches can be utilized to generate different color X-rays for pump-probe experiments.

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