RF GUN DARK CURRENT SUPPRESSION WITH A TRANSVERSE DEFLECTING CAVITY AT LCLS*

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Abstract

A significant source of radiation signals in the LCLS Undulator has been identified as being generated by dark current emitted from the LCLS RF Photocathode Gun. Radiation damage to permanent magnets over time can lead to degraded performance and significant cost for replacement. A method of using an existing transverse deflector cavity with a modified RF pulse has been tested and shows promise for eliminating the radiation dose from RF gun dark current that is generated in time before and after the production beam pulse.

DARK CURRENT IN ACCELERATOR STRUCTURES

Dark current in high gradient accelerator structures results from electrons being emitted from the surfaces of the accelerator cavity walls. With the proper phase of the electric field these particles can be captured and accelerated along with the main production beam. Even though these stray particles are accelerated within the acceptance envelope of main beam they may have slightly different energy and orbit. In FEL machines such as LCLS this dark current can be transported through the entire linac and then lost in the Undulator magnets depositing their energy into magnet material causing degradation of the magnetic field over time [1]. An existing S-Band Transverse RF deflector which is used for beam diagnostic bunch length measurements is located in the LCLS injector and is the tool used for our dark current suppression tests.

TRANSVERSE DEFLECTOR CAVITIES

RF deflector structures as in Figure 1, were developed in the early days of SLAC for use in high energy physics experiments as fast kickers to send beam to multiple experiments, separate particles with different momentum [2] or they can be used to streak the beam for measuring bunch length as in LCLS or any other beam measurement experiment. In our application as a dark current suppression device we take advantage of the fast fill time characteristics of the traveling wave deflector structure. The fill time of the S-Band deflector used in the LCLS injector is around 55ns.

This fast fill time allows us to create an rf pulse with two lobes which has a zero field between the lobes. We can time the arrival of the beam such that it sits between the lobes and is minimally perturbed while

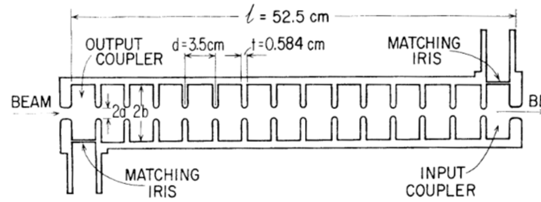

Figure 1: S-Band LOLA deflector sketch[2].

any dark current will see the maximum deflection with proper phasing of the cavity. The perturbed dark current can then be intercepted by existing collimators and purged out of the system. This scheme has been tested during several machine development days and is ready to be tested with user operation.

DARK CURRENT RADIATION SIGNAL

The LCLS undulator is instrumented with lead shielded optically stimulated luminescent dosimeters, or OSL dosimeters, electronic RADFETs, and Lucite detectors with photomultiplier tubes [1]. The initial dark current signals were observed on the PMT signals when the rf gun cathode laser was shuttered. With no production electron beam being produced there were still radiation signals present in the undulator which encompassed the rf pulse length of the gun. When power to the rf gun was taken away the signal disappeared. Even with collimation some particles which are on energy and orbit were getting through the entire linac system and depositing their energy in the undulator. A typical configuration for 9.5keV x-ray energy can yield a dose measured in the RADFET monitors of 4R/day as shown in Figure 2.

Typical Undulator Dose @ 9.5KeV
≈ 4R/Day

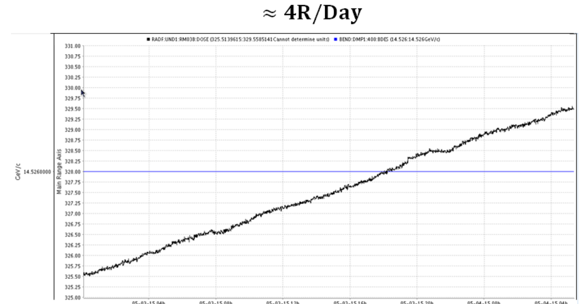

Figure 2: 24 hour RADFET 24 hour dose for 9.5KeV X-rays.

A reduction of the dose accumulated from the stray dark current electrons would be beneficial to the lifetime of the undulator magnets. The method of using the transverse deflector cavity has shown to be an effective solution in this endeavour.

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DEFLECTOR DARK CURRENT SWEEPER

RF Waveform

Initial tests of using the deflector structure as a dark current sweeper involved creating an rf waveform which would give unwanted dark current particles a kick while leaving the production beam unperturbed. The initial test was performed using a double pulse waveform with a 150ns and 50ns gap. The I&Q 150ns gap input waveform for the low level rf is shown in Figure 3a. Downmixed output waveforms from the deflector structure are seen in Figure 4.

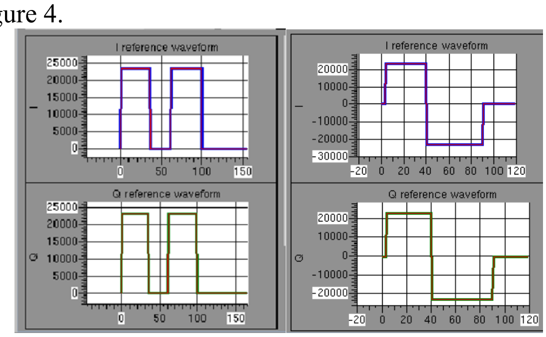

Figure 3: LCLS Control system display of I&Q waveform for dark current sweeper. 3a: RHS:150ns gap. 3b: LHS- "NoGap".

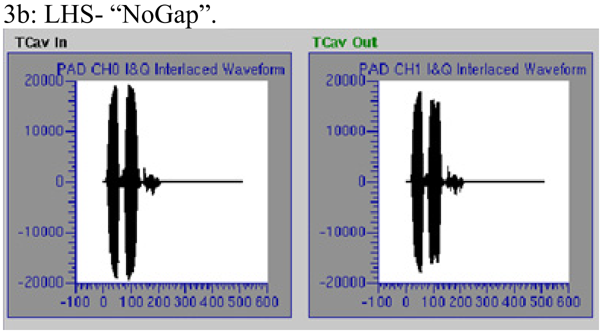

Figure 4: LCLS Control system display of Deflector RF Output with Sweeper 150ns Gap.

A waveform with a 50ns gap was also tested. Both the 150ns and 50ns gap provided the required "zero amplitude" zone which the beam could traverse the structure with little perturbation.

A final waveform with no gap, only a phase flip which results in an opposite kick for dark current which comes after the beam will be the standard running configuration when we are able to run during experiments, Figure 3. The FPGA firmware in the RF Phase and Amplitude Control Chassis (PAC) was modified to allow 30ps timing step resolution. This was achieved through shifting the FPGA clock phase. This waveform was successfully tested with beam and subsequent running will use the "no gap" waveform. The beam data in the next section was taken using the 50ns gap rf setup.

DETECTION OF DARK CURRENT IN UNDULATOR

As was stated earlier in this document and presented in [1] detection of dark current radiation signals in the LCLS undulator using Lucite Cherenkov light counters, which detect lost beam particles, were used to both characterize dark current signals and confirm the effectiveness of the deflector kicker system.

DAQ Hardware

Scintillator signals were acquired into SLAC designed DAQ hardware which is integrated into the control system. A Matlab program was written which integrates signal which displays the PMT signal as you would view on an oscilloscope. The large spike in the middle is time 0, where the FEL production beam is located. Two green boxes indicate times before and after the arrival of the main beam pulse. The image is made to have a persistence quality that allows old data spikes to fade after about 20 seconds. The image in Figure 5 clearly shows the radiation signature of dark current particles both before and after the main beam time. During our experiment we monitor this signal for some period of time and then turn on the Sweeper and observe the effect.

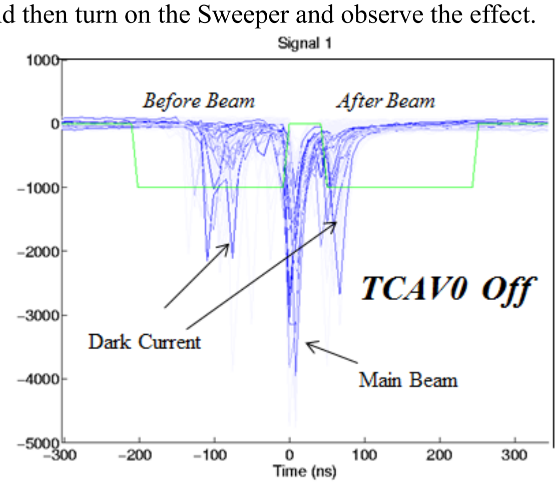

Figure 5: Dark Current Radiation observed in undulator PMT with TCAV suppression off, 9.5KeV FEL.

When the TCAV deflector operating with our double pulse waveform is enabled the radiation signature from the dark current is no longer present. A faded persistence image can be seen in Figure 6.

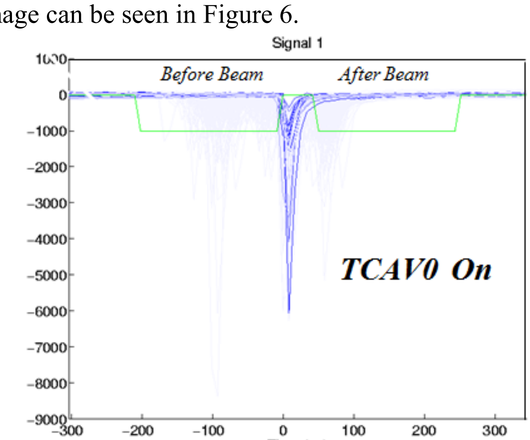

Figure 6: Dark Current Radiation is no longer observed in undulator when the TCAV is enabled with the double pulse.

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Integrated Dark Current Signals

The next test was to look at the integration of the radiation signals in time as shown in Figure 7. Scans were made looking at our 3 different detectors, 2 early in the undulator and the 3rd toward the end. The integrated signals show a clear response from having the TCAV dark current suppression system working. A more negative signal indicates more radiation detected.

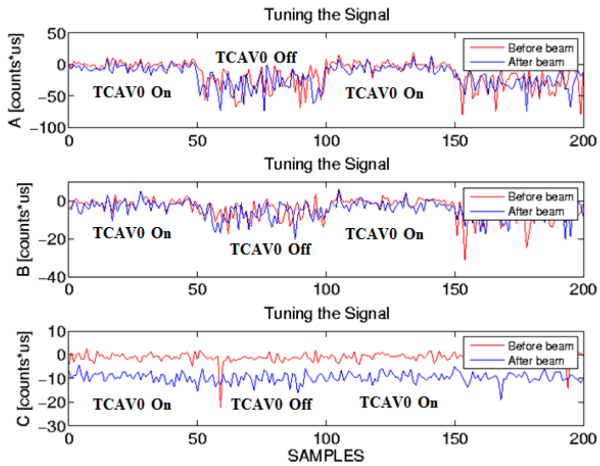

Figure 7: Undulator PMT radiation "Persistence" Scope Integration strip chart with/without TCAV0 Double Pulse Dark Current Suppression.

Integrated RADFET Signal during Operation

During one operational test we were able to leave the TCAV deflector operating for over an hour of time. This allowed a bit of dose to accumulate in the RADFET detectors. A comparison with similar running conditions a few hours before during user delivery, Figure 8, shows a 300mR/hr dose rate in a detector which is early in the undulator. For the 1.5hr integration with the dark current sweeper enabled, the detector shows an unmeasurable dose, see Figure 9. The dose rate change was not observed on other RADFET's downstream. This may indicate that the majority of dark current is lost early in the undulator.

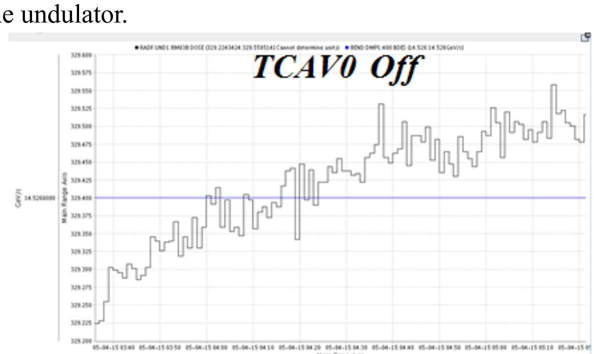

Figure 8: Typical 300mR/hr Radiation dose during 9.5KeV operation.

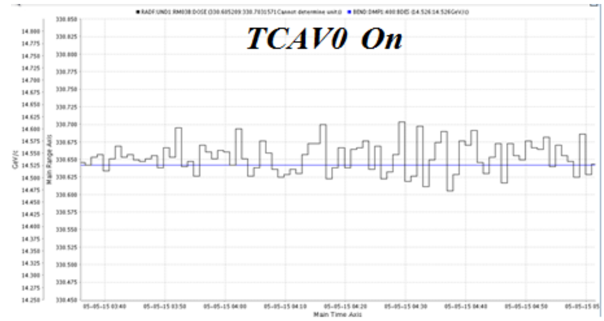

Figure 9: 0mR/hr with TCAV suppression enabled.

DEFLECTOR EFFECTS ON BEAM QUALITY

Potential concerns about passing the core beam through an active deflector cavity while operating the FEL must be addressed. Issues to be concerned about are steering effects on the beam immediately after the structure and perturbations to beam quality due to residual fields when the beam passes through the deflector structure.

Our beam tests have shown that there is no noticeable effect on the beam quality or orbit due to passing through the deflector structure with the sweeper enabled.

Figure 10 shows the beam spot immediately after passing through the deflector as viewed on an Optical Transition Radiation (OTR) foil. The orbit deflection was minimized with a 30ps RF timing trigger developed specifically for the application. A comparison of sweeper on/off shows not orbit shift.

As no detrimental effects are evident in the local vicinity of the deflector cavity we then focused our attention on downstream effects by using the XTCAV deflector in the LCLS dump line. The XTCAV is able to achieve femtosecond time and energy resolution measurements on the electron beam after it passes through the undulator magnets. Images of the beam were taken with the Dark Current sweeper disabled in Figure 11, and enabled as seen in Figure 12. There was no discernable effect to the beam quality or the FEL intensity from the sweeper operation.

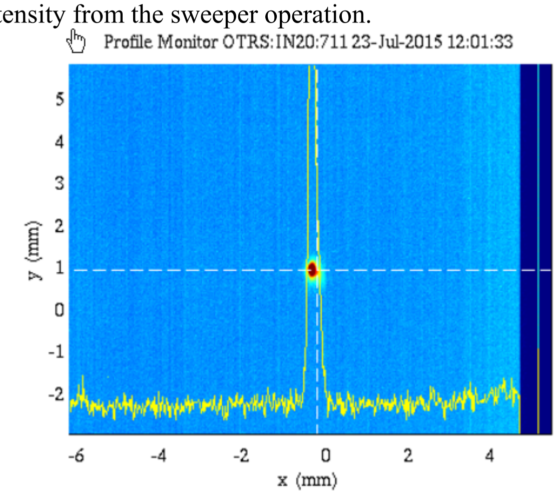

Figure 10: OTR beam image with deflector cavity enabled. Orbit corrected with fine timing of RF drive.

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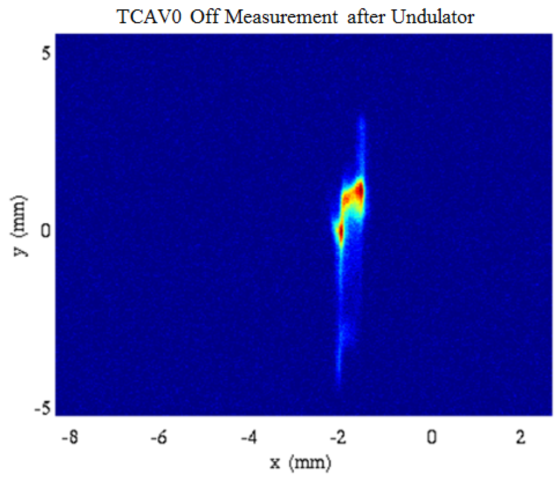

Figure 11: Beam Profile measurement after undulator with Dark Current Sweeper disabled.

During one test there was an increase in FEL energy jitter on the order of 4-5%. We are confident that with regular maintenance to this system it will perform within the operating specifications of other klystron powered systems.

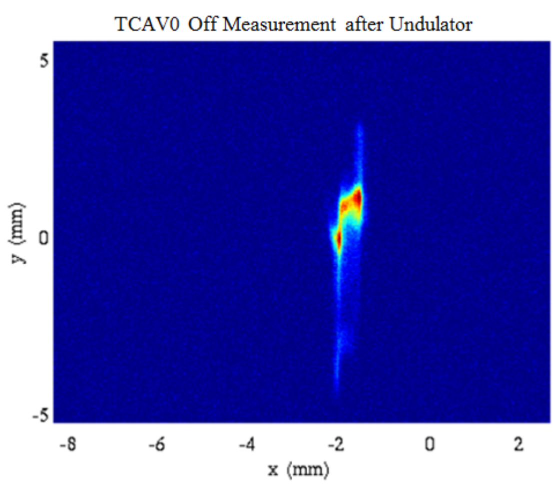

Figure 12: Beam Profile measurement after undulator with Dark Current Sweeper enabled.

APPLICATIONS FOR HIGH REP RATE FELS SUCH AS LCLS-II

Dark current that is mostly on energy and orbit can find its way through kilometre long accelerator systems, even with good collimation schemes. When pulse repetition rates of 1MHz, such as is proposed for LCLS-II, become reality the radiation doses deposited into undulator magnets from random capture of particles will accumulate very quickly. A dark current sweeper based on an rf deflector may be a good solution. Fast fill times (t_{fill}) can allow deflecting fields time to clear gaps between production beam pulses. Recent X-Band deflectors have even faster fill times and higher transverse gradients in shorter packages [3] than the S-Band structure used in our tests. For example a system based on the SLAC 27cell X-Band structure (t_{fill}=27ns) could yield a .152MV kick with 10KW input running at CW with a commercially produced klystron[4] [5].

CONCLUSIONS

A system for sweeping RF-Gun generated dark current away while leaving the production beam unperturbed has been successfully tested at the LCLS FEL operating at its usual 120Hz repletion rate. A reduction in the radiation generated by dark current has been observed when the transverse deflector in the LCLS injector operates using a special "double pulse" configuration. This added functionality can help prolong the lifetime of magnets lifetime by reducing the integrated dose absorbed in the magnetic material over time and also can improve experimental conditions by eliminating out of time particles which can contribute to experiment noise. The concept has implications for future higher repetition rate machines such as LCLS-II where the dose rates from this dark current will be much higher. It is hoped that in the upcoming run at LCLS this system can be activated for all runtime activities except those that use the deflector cavity for beam diagnostic functions.

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