ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-MOYBB6

X-RAY DETECTOR ARRAY FOR SPATIAL AND TEMPORAL DIAGNOSTIC AT THE LANSCE LINAC*

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Abstract

A recent industrial development has made possible the use of chip-scale radiation detectors by combining a Cerium-doped Lutetium based scintillator crystal optically coupled with a Silicon Photomultiplier (SiPM) as a detector. At the Los Alamos Neutron Science Center (LANSCE), there has been an ongoing effort to determine the location of high voltage breakdowns of the accelerating radio-frequency field inside of an evacuated resonant cavity. Tests were conducted with an array of 8 X-ray detectors with each detector observing a cell of the Drift Tube Linac (DTL) cavity. The array can be moved along the DTL cavity and record X-ray emissions from a section of the cavity and their timing with respect to the RF field quench using a fast 8 channel mixed-signal oscilloscope. This new diagnostic allowed us to map the most energetic emissions along the cavity and reduce the area to investigate. A thorough visual inspection revealed that one of the ion pump grating welds in the suspected area was exposing a small gap and melting copper on both sides. Sparking across this discontinuity is believed to be a source of electrons that drive the high voltage breakdowns in the drift tube cells.

DETECTOR AND TESTS

A photon absorbed in silicon will create an electron-hole pair. Reverse-biasing a photodiode will set up an electric field across the depletion region that will accelerate the electron towards the cathode and the hole towards the anode. When a sufficiently high electric field is applied to the depletion region, a single photon can trigger a self-perpetuating ionization cascade through which the silicon becomes conductive. A series resistor will reduce the electric field on the photodiode when it breaks down and limits the current caused by the photon absorption. Once the current has been stopped, the photodiode can recharge to the nominal voltage, ready to detect another photon. The time it takes to recharge to nominal voltage is the recovery time. An SiPM uses a multitude of these photodiode/resistor pairs (microcells) in parallel. The sum of currents from the microcells determines the magnitude of the photon flux [1]. Low voltage operation, inexpensive development, fast response time, lack of hygroscopic deterioration and a square millimeter size make these detectors a reasonable alternative to a traditional Thallium-doped Sodium Iodide scintillator coupled with a photomultiplier tube. Industries such as positron emission tomography, security scanners, and high energy physics calorimeters are already benefiting from the use of these devices.

Detector Construction

The chosen detector was a Ketek PM1125-WB, contain-ing 1600 microcells and with a recovery time of 30 ns. The detector alone can be used to detect high energy X-rays, but for the purposes of our application, it was used as a readout for a Cerium doped Lutetium-based crystal ($Lu_{1.8}Y_{.2}SiO_5$:Ce) LYSO scintillator that has a decay time of 40 ns. The detector output is a current, the amplitude of which relates to the number of photons received in the cell, which in turn relates to the energy of the incident X-rays. This current output was converted into a voltage and am-plified via an Advatech AMP-0611 preamplifier (Fig. 1) into a signal that could be displayed and compared with an oscilloscope. The whole ensemble was placed into a small light-sealed box (Fig. 2) with connectors that can supply the 28 VDC for the SiPM reverse biasing and the 9 VDC necessary for the preamplifier power supply.

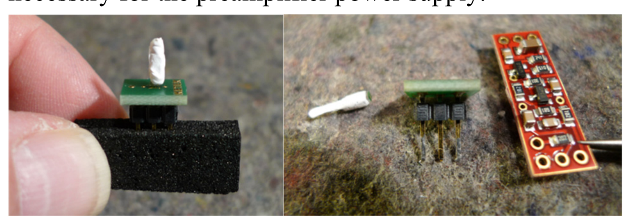

Figure 1: Scintillator mounted on SiPM detector (left), LYSO scintillator, SiPM detector and preamplifier.

Figure 2: Packaging of the full detector. The hole on the front was aligned with the collimator in the shielding and covered with opaque tape so that light would not trigger the detector.

High Voltage Breakdown Location

One of the evacuated cavities of the LANSCE 100 MeV DTL has seen an increase on the number of RF cavity field faults (fast discharge of energy stored in the cavity) for the last few years. RF field breakdowns occur between points with the greatest field gradient, which in the case of the cavity, happens to be between the drift tubes. When a breakdown occurs, the resulting spark produces light inside

* Work supported by the United States Department of Energy, National Nuclear Security Agency, under contract No. 89233218CNA000001
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the cavity and increased X-ray emissions. The electric field in the cavity collapses and a derivative circuit processes this rapid collapse, creates a logic signal and shuts off RF going into the cavity for the duration of the remaining RF pulse and the resulting spark is extinguished [2].

Previous diagnostics relied upon fiber optic detectors viewing the cavity through small apertures with quartz windows. These IR detectors require a physical line of sight into the cavity and they are affected by the numerous reflections that the polished surfaces inside the cavity can produce. An arc in the tank will also emit X-rays that can be measured from outside the cavity and their intensity is greater around the drift tubes that suffer the breakdown. To isolate the sections that were causing the RF field to collapse, a total of 8 detectors were constructed and each was placed in front of a different gap of the cavity. The devices were placed on top of rolling tables whose height was adjusted to be directed towards each of the individual gaps and that could be moved along the length of the cavity to look at different sections. To prevent devices from being influenced from X-rays emanating from an adjacent gap, a lead brick with a cylindrical collimator was placed on the front and two solid bricks were shielding the side of the devices.

First Tests and Shielding

During the first tests (November-December 2018), two issues became apparent that made us realize the need for better shielding of the detectors. The signal used to shut down the RF into the cavity when a breakdown occurs was used to trigger a fast 8 channel mixed-signal scope and record the level of X-ray radiation at each of the DTL cavity gaps that the detectors were observing. In this application, temporal diagnosis is not a primary concern, since the event triggering the X-ray emissions is known.

Initially, the detectors were placed on 2 different supporting tables and each device was shielded by only 3 lead bricks (Fig. 3). Our first results revealed that the X-rays emanating from the breakdown were visible on all the detectors independently of their position, which meant that better shielding was needed to prevent cross detection. A complete housing made of 14 solid lead bricks (Fig. 4) and a single perforated brick at the front to act as a collimator was built for each device to look at a single gap of the DTL. Crosstalk between individual sensors was greatly reduced because of this improvement.

During the next batch of tests, it became apparent that backscattered X-rays from another cavity would be recorded by the sensors and contaminate the results. The maximum gap voltages on the other cavities of the 201 MHz part of the linac are: 340 kVp (Cavity 1), 1.03 MVp (Cavity 2), 1.31 MVp (Cavity 3), 1.46 MVp (Cavity 4). All of these gap voltages are high enough to produce X-rays when RF is fed into the cavities [3]. A lead blanket was added on the back of the housing (needed opening for the cables that feed the 9 and 28 VDC to the detectors) and the X-rays emanating from other cavities nearly disappeared on the waveforms of the sensors.

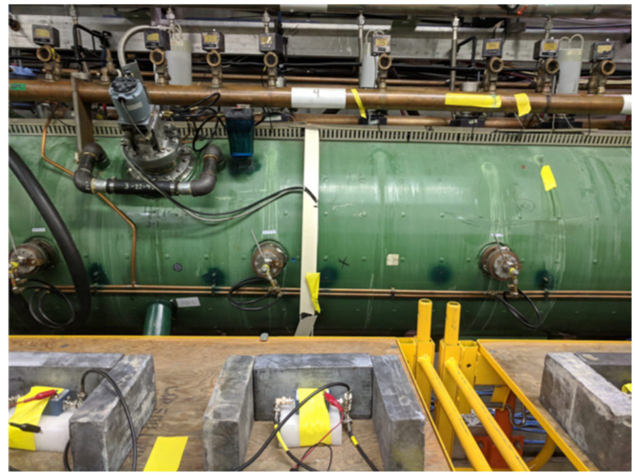

Figure 3: Detector placement for first test. The brick on the front has a 1 cm hole to act as a collimator and limit the detector's field to only one gap of the cavity. This three-brick housing proved ineffective in shielding the detectors from X-rays being produced in adjacent gaps.

Figure 4: Lead blanket added to shield the detectors from backscattered X-rays emanating from adjacent cavities and final configuration of the detectors.

Diagnosis

The detectors were subsequently placed in front of different sections of the cavity, to locate the highest energy emissions and possible source of the high voltage breakdowns. The highest amplitude detected during most of the breakdowns was on the gaps on the second quarter of the tank (Fig. 5). The highest peaks were found mostly at the center, but throughout the many faults, the maximum amplitude voltages could be traced to different gaps in the same section. The results pointed to the cause of the breakdowns being in this particular portion of the cavity.

An extensive visual inspection by means of a high definition camera and a borescope was conducted. In the middle of the suspected section, there is a grating welded to the tank's inner wall that allows for the flow of current along the wall whilst also allowing for gas molecules to be pumped from the cavity through the openings in the grating.

North American Particle Acc. Conf. NAPAC2019, Lansing, MI, USA JACoW Publishing
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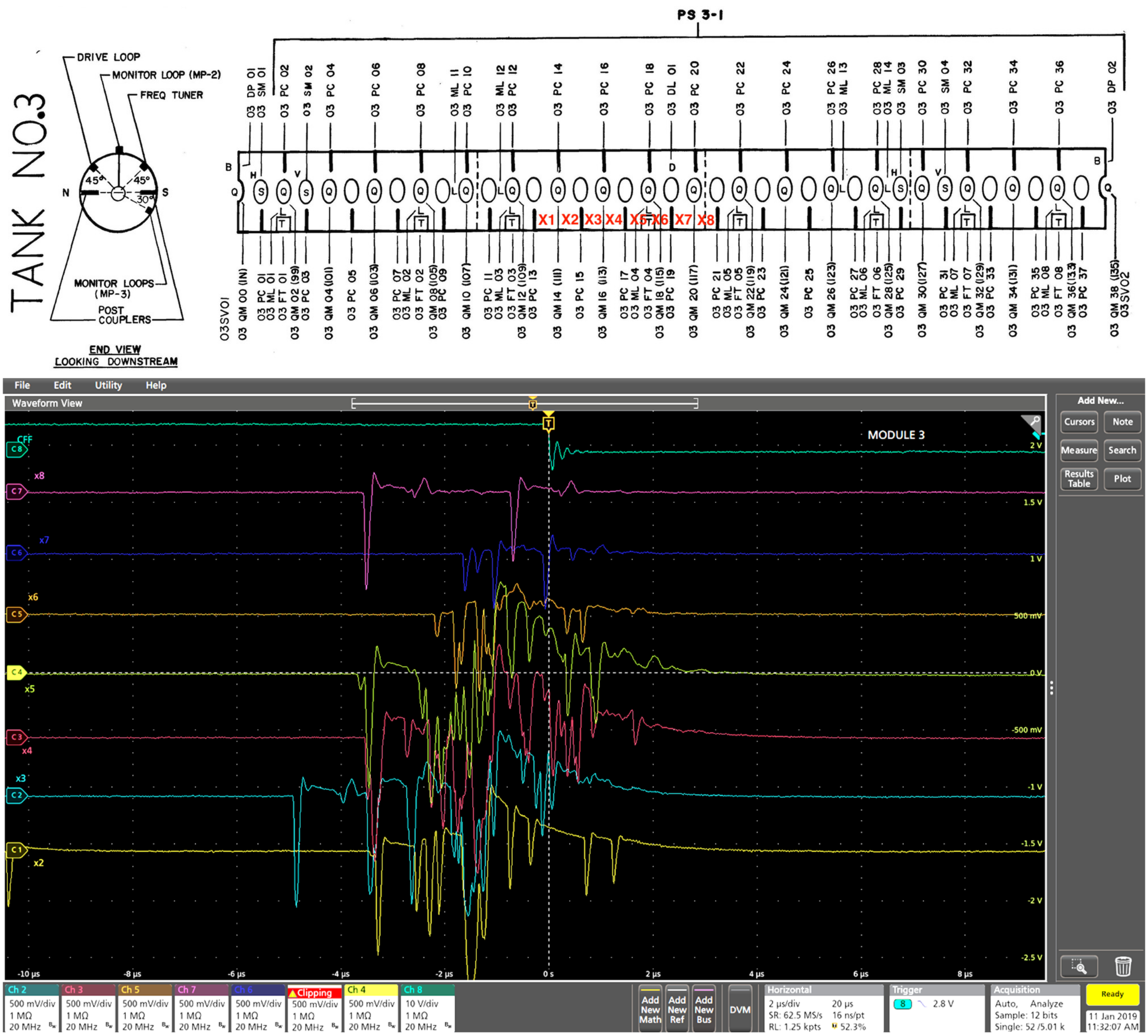

Figure 5: The most energetic X-rays are registered on the second quarter of the tank. The detectors have a negative output and due to the AC coupling of the amplifier, after every X-ray emission received there is a positive offset displayed.

One of the welds perpendicular to the longitudinal axis of the linac was presenting a gap that was perturbing current flowing across. Sparking across this section could be the source of UV light illuminating onto the cavity gaps and creating excess electrons, causing the RF field to quench. On multiple occasions the RF field decay presented a slope (several µs) that suggests the UV was altering the field and causing electron loading at the gap even before the arc event (Fig. 6). This event was only observed in open loop, when the LLRF system does not regulate the RF field. Similar observations have been recorded in which the breakdown was found to be related to light emitting points produced by heating on the surface of a cavity [4].

The cavity was returned to full operation after a copper patch was designed and welded to the inside of the tank wall to bridge the discontinuity presented to the current.

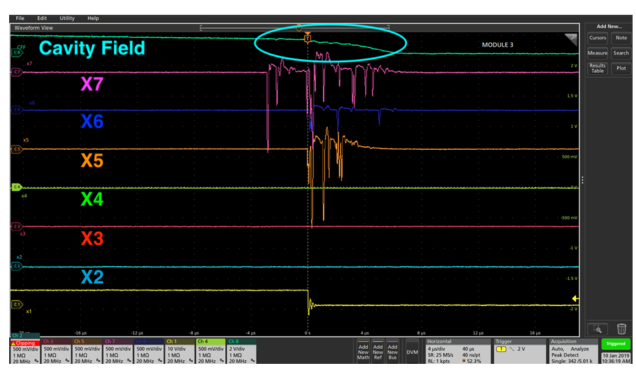

Figure 6: The RF field presents a slower drop that is accompanied by X-ray emissions from the start.

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