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Field Radiography with Advanced Digital Detector Arrays (DDAs): Improving Safety & Speed

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Abstract

Over recent months, large strides have been made in application development and utilization of Digital Detector Arrays (DDAs) in field radiography environments. The use of DDAs in aerospace aircraft assembly and many oil and gas applications from upstream insulated pipes to midstream flow lines and downstream valves inspection have proven to significantly reduce exposure times versus film and computed radiography techniques. This substantial reduction in exposure time not only increases productivity, but also improves safety by decreasing the time the radiation source has to be exposed as well as in some cases allows for a decrease in source strength.

The astonishing reductions in exposure times are enabled by the core design concepts of DDA technology, original developed for medical applications. Many of the same design principals to protect doctors and patients from radiation exposure by optimizing not only image quality but ensuring the all x-rays are captured and utilized efficiently to create the image. By leveraging the core technology from the medical industry with some industrial specific modifications, the DDA has proven to be a viable and advantageous inspection tool for field applications.

Keywords: Digital Detector Array (DDA), oil and gas, aerospace.

1. Introduction

Over recent months large strides have been made in application development and utilization of Digital Detector Arrays (DDAs) in field radiography environments. The use of DDAs for this applications show benefits of significantly reduced exposure times versus traditional film and computed radiography techniques. These results are enabled by the technology investment and focus of the medical image quality to achieve image quality, but with respect to dose. Unlike cabinet based radiography, where dose is less important as humans are shielded from the x-ray exposure; field and medical applications must take this into greater consideration. This was a major factor in DDA design and choices for photodiodes, scintillator and display electronics.

2. Applications and Enabling Technology

2.1 Application Development and Utilization

Applications development efforts over recent months have led to the wide acceptance and use of DDAs for field inspection, an application previously limited to film and computed radiography techniques. These application development efforts have included and proven successful implementation in a wide range of field applications from both the oil and gas and aerospace industries. In both industries, significant reductions in exposure times have been realized by utilizing DDAs for radiographic inspection versus traditional film and computed radiography techniques. The reduction in exposure time not only enables productivity through shorter shot times, instant availability of images for review and analysis; but also improves overall safety to radiation workers and other employees by decreasing radiation source deployment or on-time and in some cases allows for a decrease in energy or source strength.

2.1.1 Application Example

There are many examples where DDAs have shown significant benefits over film or computed radiography. One of these examples is in the oil and gas downstream inspection of valves. The same inspection plan was completed utilizing both computed radiography and a DDA. The image quality results were similar or improved utilizing the DDA, but the exposure time results were remarkably reduced.

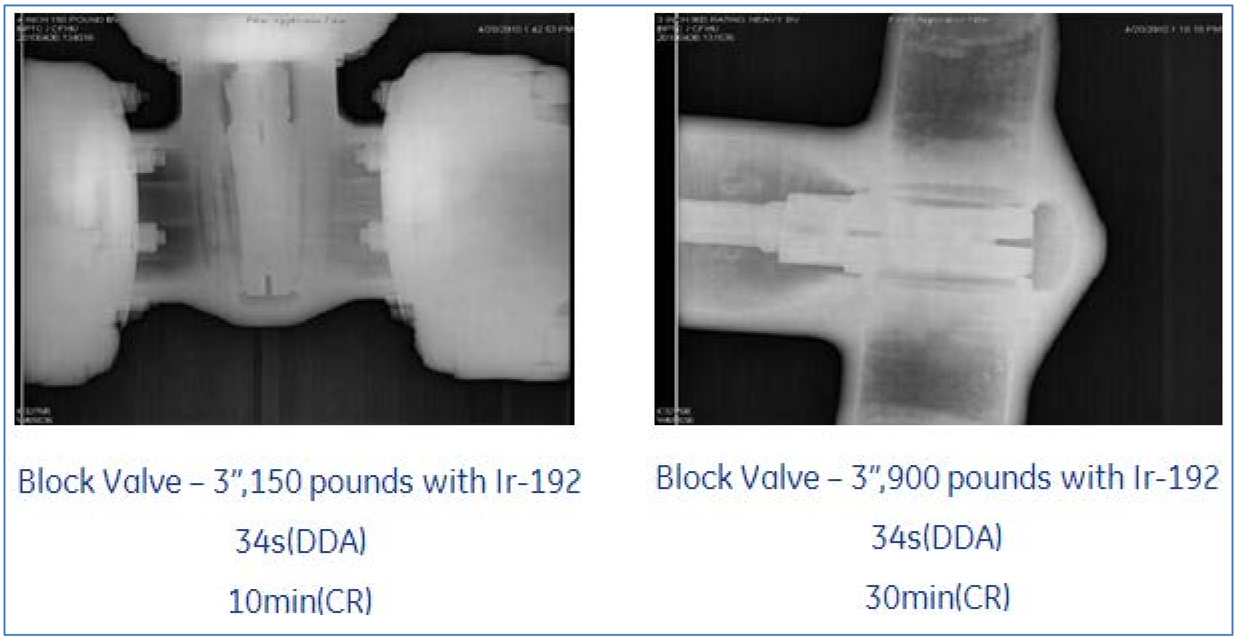

Figure 1: Two application examples showing comparing DDA and CR exposure times

2.2 History of DDA Innovation

The medical industry began developing DDA technology over 25 years ago, spending millions of dollars in the initial 10-year development cycle. Since initial introduction, technology investment has continued, focusing on two critical areas: image quality for visualization of relevant features and dose reduction for improved doctor, healthcare worker, and patient safety. The focus on optimization of image quality with respect to dose is one of the key aspects leading to the successful implementation into industrial field applications, where radiation safety is a critical consideration versus environments where shielding and radiation protection cabinets can be utilized.

2.3 DDA Design Considerations

As the first DDAs were developed, there were many design considerations taken into account as the technology moved from analog to digital. Maintaining the ability to image in a large format, resolution and the efficiency for converted x-rays to images were primary considerations in the design process. These requirements translated into specific design features and choices in the pixel design, scintillator choices and the development of display electronics to create a DDA with optimized image quality and minimized input dose.

2.3.1 Pixel Design

Each DDA contains millions of individual pixels; the design of those pixels must consider many elements. A few of the many elements considered during optimization were photodiode leakage, radiation hardness, electronic noise, x-ray utilization, image size and manufacturability.

Amorphous Silicon (a-Si) was chosen over Crystalline Silicon (x-Si) technology due to its elemental structures being less susceptible to radiation damage, the lower leakage characteristic of the photodiodes and manufacturability, leveraging the equipment and processes developed by the LCD industry. Using plasma-enhanced chemical vapor deposition (PECVD) the desired large formats are achieved without the problematic tiling of many smaller x-Si wafers. The key trade-off associated with this choice was speed of the thin film transistors; a-Si can be an order of magnitude faster.

Choosing optimal pixel size also underwent much consideration. Smaller pixel sizes provide better resolution; however produce noisier images and require more doses due to fewer x-rays being captured in the photosensitive diode and smaller fill factors. It became imperative to find the optimal size allowing the resolution to visualize relevant features for the application while maintaining high levels of x-ray utilization to minimize dose requirements. Often a 200 micron pixel size is chosen to provide optimization of resolution, noise and dose. However, some applications require higher resolution to see relevant features and smaller pixels sizes, such as 100 micron, are chosen factoring in slightly more noise and dose.

2.3.2 Scintillator Options

Two types of scintillators are common across both medical and industrial applications: Cesium Iodide (CsI) and Terbium-doped Gadolinium Oxysulfide (GdOS:Tb, GOS). CsI is a structured scintillator vapor deposited as columnar needle-like structures. This shape helps funnel x-rays efficiently to the diode array; a reflector is often used to redirect any stray x-rays also aiding in overall efficiency and image quality. A common drawback to CsI has been its tendency to “ghost” or display latent images. Some manufacturers have improved this effect through enhanced formulas and thicknesses. GOS can be a more cost-effective scintillator choice and can perform comparably to CsI in terms of x-ray efficiency in some energy ranges. Each scintillator choice is a viable solution for industrial applications and the user must compare the trade-offs between cost, efficiency and ghosting. For the oil and gas field applications discussed, a GOS scintillator was chosen for the oil and gas applications due to cost and tendency to be utilized in conjunction with isotope sources. In the aerospace aircraft assembly applications, a CsI scintillator was chosen for image quality and its efficiency at lower x-ray energies.

2.3.3 Readout Electronics

The readout electronics are responsible for the final conversion of the electrons into useful digital data. Considerable effort was put into the scintillator and photodiodes to reduce noise and efficiently utilize x-rays; the readout electronics must continue this through the delivery and presentation of high image quality to the end user. Pixels are read out through fast and complex multiplexing, where only micro seconds can be spent reading out each line containing thousands of pixels. The low leakage in the thin-film transistor (TFT) and low noise high-performing, application-specific integrated circuits (ASICs) are the keys to enable efficient multiplexing. The ability to maintain a low-noise floor in the electronics allows the design considerations and choices in the amorphous silicon diode array and scintillator to be realized in the final image.

2.4 DDA Manufacturing

By choosing Amorphous Silicon for the pixel design, manufacturing DDAs leverage the processes and equipment from the billion-dollar LCD industry. Beginning with a piece of glass, the DDA goes through a cyclical process of thin film deposition, photo lithography pattern and development, pattern etch, pattern strip then finally inspect and test until the desired number of layers for the pixel design are achieved. The scintillator is deposited either through vapor deposition or a laminator depending on whether CsI or GOS is chosen. Readout electronics are then bonded, requiring thousands of connections, to the panel and the unit is tested as a DDA. After test, the detector is put into final packaging.

3. Conclusions

Many of the design choices and investments made in the medical industry to achieve required image quality, while keeping the x-ray dose minimal for doctor and patient-safety translate directly to industry for field applications, where radiation safety is a major concern. The choices in photodiode, scintillator and electronic technology allow for the efficient conversion of x-rays leading to the results shown in the application examples results.