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Spanning the range: Film to CR to DR

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Abstract

Radiographic Testing is used in a wide range of industries anywhere in the life cycle of a product or component. Industries span aerospace, automotive, oil and gas, electronics, and security to name a few. Applications include verification of a good manufactured part, to corrosion and fatigue monitoring on aircraft or pipes. Each of these applications has different requirements for speed and image quality at a cost appropriate for the desired results. Many examinations require techniques that meet industry standards. In selecting an x-ray system, other factors such as environmental and regulatory considerations may also be important. Of the detection system options currently available, radiographic film, computed radiography and digital radiography are widely used today. Within these main groups, there are often options for variations to meet quality/speed requirements. A simple outline of inspection considerations has been developed to assist users in narrowing the options appropriate for the application/industry at hand.

There are two scenarios for acquiring radiographic testing equipment. The first scenario is one where an existing radiographic facility already exists, and upgrades are sought to augment either performance and/or speed, or to reduce costs. The second scenario is that of a new facility, perhaps envisioned to take advantage of a new technology, or to address a new inspection need not encountered previously. The latter scenario typically involves a complete system solution and involves numerous parties on the buy side as well as on the supply side to ensure that all customer requirements are met and that the final solution provides financial value.

For this discussion, film is defined as any of the industrial NDT films used, with or without Pb intensifying screens, that are developed in film processors; CR plates are computed radiography storage plates based on a photostimulable phosphor screen that stores a latent image in the phosphor that is then read-out by a laser scanner; DR systems are those using detectors that provide static or real-time radiographic imagery that is transferred directly to a computer without having to remove the device for further processing. In the past 10 years, an emerging technology in the DR category is the amorphous silicon detector. These detectors utilize thin-film-transistor technology to capture and read out an image from a phosphor or a photoconductor that is in intimate contact with a semiconductor photoarray. Other DR detectors include CCD, CMOS, and linear photodiode arrays where the latent image is also captured in a phosphor or photoconductive material. Lastly, image intensifiers linked to video camera systems have been widely used and can provide analog as well as digital results.

Factors that impact radiographic system selection

Several factors influence the decision to purchase a radiographic system. These include image quality, the range of applications the detector will be used, the accessibility of the device into the location under examination, the speed requirements for the range of applications, artifacts prevalent with the devices, costs to purchase and operate the device and the associated infrastructure, and available standards to assure consistent industry results. Embedded in this discussion are radiation safety issues and environmental concerns such as temperature and risk to damage through impact or shock that are typically encountered in field testing or open environment (no enclosed shielding) testing.

***Image Quality*.**

In nondestructive testing, as in medical imaging, the quality of an image to achieve the required detection capability depends on the signal-to-noise ratio within the image of an object and the spatial resolution associated with that image. A metric that best defines the overall performance and efficiency of a detector system is the detective quantum efficiency, which includes the signal, noise, spatial resolution and required exposure level. If a wide range of inspection applications and high-speed imaging and throughput are of dominant interest, the device with the highest detective quantum efficiency is then the desired choice. But frequently, one of these three parameters (speed, contrast or spatial resolution) can be relaxed in order to achieve either higher performance in the other two, or obtain some other benefit in system selection.

Digital radiographic detectors based on amorphous silicon detectors have high detective quantum efficiency because a high gain scintillator or photoconductor absorbs, converts, and efficiently transfers much of the x-ray energy to the amorphous silicon read-out device. However, these digital detectors may not have sufficient spatial resolution to detect the smallest indications, such as tight fatigue cracks. If microfocus magnification radiography is not an option, film radiography or computed radiography in a high resolution scanning mode may be able to achieve the task, and do this over reasonably large areas. Conversely, low contrast gross features require good depth discrimination and a good signal to noise ratio, but do not require high spatial resolution. In these cases, digital or computed radiography may offer both contrast and speed advantages over film techniques. The application engineer must decide which factors are most important for the business at hand. Once a system approach is selected, that system must be tested under expected inspection conditions to validate that the system meets desired image quality levels.

***Range of Applications*.**

Many industries require a wide range of materials and thickness to be inspected within a factory or in the field. This may require that the x-ray energy span a range from only a few kilovolts to many million volts, to penetrate such diverse materials as composite flight control surfaces to steel landing gear. It would be convenient if the detector could be configured to operate within this range as needed. Film and computed radiography detectors have been successfully used in this range. DR systems have had only limited history at the higher energy range, where some of their fundamental advantages may be offset by physical limitations.

In a similar vane, the use of a range of gamma ray sources of varying energies and activity may need to be accommodated by the detector system. In many cases, the activity of an isotope is selected so that they can be used within a limited radiation safety zone. This then requires the detector system to be very sensitive and/or have the ability to allow long exposures, so that the signal rises well above the noise floor of the device. Although DR systems have excellent DQE and sensitivity, some devices have limited exposure time capability. If the signal in an individual frame is not high enough above the noise floor at the exposure time limit, no degree of image averaging will help in the final averaged image. In circumstances where DR detectors can provide good image quality, their selection may be preferred for the increased speed, assuming all other image quality requirements are met.

Yet other applications require the use of microfocus x-ray techniques to detect very minute defect indications, typically less than 25 microns (0.001-in). In this case, sensitivity is again a top priority and DR systems, both static and real-time offer significant speed advantages. Although film techniques can be used with a microfocus x-ray tube, the relatively low output of these tubes could result in exposure times that run many tens of minutes. Conversely, some DR systems have been shown to operate in real-time achieving a spatial resolution better than 10 microns (0.0004-in) using these tubes and a rate of 30 frames/sec. Some of these devices also offer the capability to perform static imaging or image averaging to achieve better sensitivity. For example, once a defect or a feature has been identified, a longer exposure of that area can be obtained to increase the signal-to-noise ratio and improve defect analysis and discrimination.

Inspection Accessibility.

Many applications have limited access, such as inside a complex castings or jet engines. Yet other applications require large coverage, but over a curved surface. In other specialized examinations, small detectors are required to gain access. In these cases, film and CR systems are the preferred method because they can be configured to fit inside these areas and can be shaped or cut to meet the application. Although small area DR systems are coming online, their performance has not yet been verified for these applications, they have limited area, and are not flexible. Some large area DR systems are quite thin and can be used where other environmental issues such as high temperature, impacts or other forms of shock are not present. However, the risk of mechanical damage is often better managed with film or CR sheets, where shock and impacts may not alter their performance.

***Total speed of inspection*.**

The speed of acquisition has already been discussed above. The ultimate critical factor for some businesses may be the overall speed to results and interpretation. In production lines, or in field applications where limited time is available to get successful exposures, it is necessary to have the correct answer before moving to another location. In these circumstances, for example where films or CR image plates are not "plastered across a structure", real-time or near real-time results fully impact the time and cost not only of the inspection itself, but also to the surrounding processes. For example, work on an aircraft is usually halted during radiography. During many radiographic examinations, one particular radiographic set-up cannot be moved until an approved exposure and results are obtained. If using film, or even in some cases a CR plate, it may take several minutes to process the image before knowing if further exposures would be necessary in that local area. In these circumstances, it may be more cost effective to use fast DR systems where results are obtained almost instantaneously. This enables related processes on a structure to get back on-line more quickly, thus enhancing overall maintenance productivity.

In those cases where results need not be known immediately and subsequent exposures can be obtained without concern of a prior exposure, another approach to rapid inspections may be to "plaster" numerous films or CR plates onto the structure. Then a simple motion of the x-ray tube or isotope along this array of detectors is easily achieved at low cost. Then, following the exposures, processing may be achieved in bulk, and review can be done at a time either during or following the acquisition phase of the examination. This approach is cost prohibitive for a DR system as multiple detectors would not be practical, but a manipulator housing a single detector can be assembled to effectively mimic this method, of course at slower inspection speeds.

Lifetime/Artifacts.

All detectors, whether film, CR plates, or DR panels, can demonstrate artifacts. With film, creases or minor bends on the film manifest themselves as false indications on the resulting processed sheet. In these cases, if such an artifact appears, the inspector might request a new film be exposed. Similarly, CR plates and their lead intensifying screens can develop nicks and scratches that show up on the image, which may be uncorrectable. At this point, it might be prudent to retire the screen and place a new one in service. DR detectors are less prone to damage in this manner as they are protected by cover sheets, but can develop artifacts from radiation exposure. Although radiation effects are dependent on the total dose, the rate of exposures, and the intensity and energy of the x-ray environment, some DR detectors will develop artifacts over time, and at that point the detector must be replaced. Since these effects depend on all of these parameters, predicting the lifetime in terms of total Roentgens of exposure or years of service requires a careful analysis of the application. In some cases, the productivity benefit of fast digital data must be weighed against replacement or service costs.

Another artifact that may be present in DR detectors is ghosting. This artifact occurs when a phosphor retains a history of prior radiation and is revealed in the current image or real-time sequence. Ghosting can potentially provide false positive indications or might even hinder the detection of true positive indications. If this artifact occurs, it can ordinarily be controlled or reduced through x-ray beam filtration or a revised inspection set-up. Not all systems have ghosting, and it is best to test the system for the application at hand to determine if this artifact impacts the inspection process.

With the current manufacture of digital detectors that involve millions of pixels, it is possible that some small number of pixels do not operate properly after manufacture. Unlike film manufacture that has about 100 years of manufacturing experience behind it to achieve near perfect film emulsions, digital detectors can have occasional isolated non-responsive pixels, clusters and lines that can be interpolated. If the number or distribution of interpolated pixels, clusters or lines becomes too high, these can hinder detection of a possible defect in the image. The allowable distribution should be determined by understanding its impact on the overall probability of detection for the inspection process. No standards for these artifacts have yet been established and each application must be evaluated.

The mere presence of pixels with non-uniform response in an image can be a distraction, and in most applications it is preferable to have these pixels corrected by using interpolation techniques from nearest neighbors. However, in rare cases it might be best not to interpolate, or better, to flag the bad pixels so that if a potential defect appears to be present in an affected area, the NDT operator can move the part or detector and acquire a second view to determine the true extent of this possible defect.

Purchase cost and inspection cost.

A typical means to justify a purchase cost is to determine how fast the system will pay for itself considering future operating costs. The Air Force recently purchased an automated F-15 inspection system that will take about 1 year to recoup the purchase and installation cost over the prior method of inspection. But other factors come into play, such as there existing radiographic cells and other infrastructure, and upfront capital to make the change. In comparing whether to purchase a film, CR or DR system, are darkroom facilities pre-existent, or would space and funds have to be allocated for this infrastructure. A robotic scanning system using digital detectors may in fact save millions of operating dollars over a CR or film inspection, but how do the capital costs must be compared to a simple film approach, especially if the infrastructure for the dark room and processors already exist. The cost/benefit tradeoff of digitization and rapid dissemination of information needs to be considered in this discussion as well. These factors as well as maintenance and other recurring costs need to be considered and weighed against the discussions in the above sections. In many situations, it might be best to have both technical and financial analysts on the team to weigh all of these options.

***Industry Standards*.**

Over the decades that NDT film has been in use, a series of international standards have been devised to accommodate every aspect of film radiography, from film processing standards to image quality to calibration of film densitometers. In the areas of CR and DR, only recently have standards been introduced. What is needed is to obtain a full slate of standards that deal with the same issues that film standards have dealt with, from acquiring and processing the images, to assuring adequate image quality to dealing with new issues such as bad pixels and other artifacts. Until these standards can be implemented, it is up to the cognizant purchasing engineer and the NDT system supplier to address these issues on an individual basis. In some industries, the lack of standards prohibits the purchase of new technology. In selecting a system, it is best to fully understand what the industry or individual company specifications dictate for standards compliance prior to getting too deeply entrenched in all of the above discussions.