Digital Detector Array Image Quality for Various GOS Scintillators

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Abstract

Digital detector arrays (DDAs) are becoming more prevalent for industrial radiographic inspection. The type of scintillator used with a DDA determines the overall achievable image quality. DRZ High, DRZ Plus, DRZ Standard, and DRZ Fine gadolinium oxysulfide terbium (GOS: Tb) activated scintillators were investigated in combination with the Carestream DRX PLUS digital detector array panel. Three beam conditions were utilized for exposure: RQA-5 (70 kVp, 21 mm aluminum), RQA-9 (120 kVp, 1 mm copper and 4 mm aluminum), and NDT (220 kVp, 8 mm copper). The detective quantum efficiency (DQE), modulation transfer function (MTF), sensitivity, and interpolated basic spatial resolution (iSRb) were determined for each scintillator and beam condition. The results of this investigation are presented in this paper.

1. Introduction

DDA technology is gaining acceptance within the NDT industry due to workflow advantages¹,²,³,⁴. Nearly all medical radiological applications have converted to indirect DDAs. DDAs are electronic imaging devices that convert X-rays or gamma rays to light, which is stored as a voltage and is subsequently sampled to form the digital image. There are two common types of scintillators for radiology and radiography: cesium iodide thallium (CsI:Tl) and GOS. CsI-type scintillators are not commonly used for industrial radiography because of ghosting issues above 150 kV; therefore, GOS-type scintillators are almost always chosen for NDT applications.

GOS scintillators are optically coupled to glass that contains a patterned array of pixels. Each pixel contains a photodiode, which senses the light from the scintillator, and a thin film transistor (TFT), which stores the charge created by the photodiode. The thickness and phosphor size of the scintillator largely influence the overall quality of the digital image, which is a combination of brightness, sharpness, and noise.
DQE is a measure of image quality as a function of spatial frequency, and it is defined as:

\[
DQE(f) = \frac{q \cdot g^2 \cdot T^2(f)}{NNPS(f)},
\]

where \(DQE\) is the detective quantum efficiency, \(f\) denotes that the term is a function of spatial frequency, \(q\) is the density of incident quanta per unit area at the detector (flux), \(g\) is the system gain, \(T\) is the MTF, and \(NNPS\) is the normalized noise power spectrum.

The DQE provides a quantitative way to measure the detection capability of an imaging system for given exposure parameters as a function of spatial frequency.

MTF is a way to measure the achievable detail that a system can obtain. The MTF describes the contrast of an image as a function of spatial frequency. MTF is calculated by measuring the edge response of a tungsten phantom with a very sharp angle. A line profile is drawn in the radiograph across the sharp angle, resulting in an edge spread function (ESF). Taking the derivative of the ESF results in a rate of change across the angled edge, which is known as the line spread function (LSF). An oversampled LSF has a Fourier transform applied to it to yield the contrast modulation as a function of spatial frequency, as the Fourier transform decomposes the LSF into the frequency domain.

Basic spatial resolution (SRb) is a measure of the amount of detail that can be seen in an image with a duplex wire gauge placed directly on the detector. The duplex wire gauge consists of several elements. Each element has two wires with a specific diameter and spacing between them. In an image, a line profile is drawn perpendicular to the elements. The element is said to be resolved if the intensity difference is greater than 20% of the wires against their background.

### 2. Experimental

Four different GOS-type scintillators were investigated in combination with the Carestream DRX PLUS DDA for three different X-ray beam conditions. Table 1 describes the GOS scintillator types that were investigated.

<table>
<thead>
<tr>
<th>Scintillator Type</th>
<th>Support Thickness (µm)</th>
<th>Phosphor Thickness (µm)</th>
<th>Overcoat Thickness (µm)</th>
<th>Total Thickness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRZ Fine</td>
<td>250</td>
<td>110</td>
<td>6</td>
<td>366</td>
</tr>
<tr>
<td>DRZ Standard</td>
<td>250</td>
<td>140</td>
<td>6</td>
<td>396</td>
</tr>
<tr>
<td>DRZ Plus</td>
<td>250</td>
<td>210</td>
<td>6</td>
<td>466</td>
</tr>
<tr>
<td>DRZ High</td>
<td>180</td>
<td>310</td>
<td>9</td>
<td>499</td>
</tr>
</tbody>
</table>
The DRZ Plus screen is always chosen for DDAs that utilize GOS for medical radiology. The DRZ Standard screen is normally utilized for NDT applications; however, the DRZ Fine screen has been introduced for DDAs with smaller pixel pitch. We wanted to determine, through scientific analysis, the best scintillator for our DRX PLUS DDA panel, which has a pixel pitch of 139 µm.

The four GOS-type screens were placed in pressure contact with a TFT photodiode array. Exposures were performed with standardized beam conditions, RQA-5 and RQA-9, which are used in medical radiology, and NDT, which is commonly used for industrial radiography. Individual images were acquired for the dark calibration, gain calibration, flat-field noise power spectrum, slanted-edge MTF target, and duplex wire gauge. MATLAB was utilized for the analysis of the DQE and MTF. For the DQE comparisons, the exposure was adjusted to match the DRZ Plus signal level.

3. Discussion

As the thickness and phosphor size of the GOS scintillator is changed, the brightness, sharpness, and noise of the image changes dramatically. Most radiographers do not realize that the scintillator choice determines the image quality of the DDA, and it is often overlooked and taken for granted. Thinner GOS scintillators with smaller phosphors will result in images that are sharper, with reduced brightness and improved noise uniformity. Likewise, thicker GOS scintillators with larger phosphors will result in images that have reduced sharpness, with increased brightness and degraded noise uniformity. The balance of the sharpness and the signal-to-noise ratio will determine the overall image quality. Therefore, the proper choice of scintillator determines whether or not the DDA can meet inspection requirements.

The brightness of the scintillator helps to determine the amplification or gain of the system. Brighter scintillators can result in improved image quality if all else is equal. Relative to the DRZ Plus, the DRZ Fine was 2.0 times less sensitive, the DRZ Standard was 1.27 times less sensitive, and the DRZ High was 1.40 times more sensitive for the RQA-5 beam condition. Table 2 provides a comparison for the two different beam conditions.

<table>
<thead>
<tr>
<th>ADu per mR</th>
<th>RQA5</th>
<th>RQA9</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRZ Fine</td>
<td>2224</td>
<td>2607</td>
</tr>
<tr>
<td>DRZ Standard</td>
<td>3503</td>
<td>4132</td>
</tr>
<tr>
<td>DRZ Plus</td>
<td>4445</td>
<td>5477</td>
</tr>
<tr>
<td>DRZ High</td>
<td>6229</td>
<td>7871</td>
</tr>
</tbody>
</table>
The overall image quality was measured by DQE analysis. Figures 1, 2, and 3 present the DQE results for the four GOS screens at the three beam conditions. The DRZ Standard scintillator had the best DQE above 2 cycles/mm. Below 2 cycles/mm, the DRZ Plus scintillator was the best choice as the DRZ High lacked sufficient sharpness for consideration. The DRZ Fine screen did not have suitable image quality except at very high spatial frequencies. As the kV increased, the overall achievable image quality decreased.

Figure 1: DQE Comparison for RQA5, 70 kV, 21 mm Al DRZ scintillators.

Figure 2: DQE Comparison for RQA9, 120 kV, 1 mm Cu and 4 mm Al DRZ scintillators.
Figures 4, 5, and 6 present the MTF results for four different screens at the three beam conditions. The sharpness of the DRZ Fine scintillator was clearly the best across all spatial frequencies, followed by the DRZ Standard, DRZ Plus, and the DRZ High. The sharpness decreased at higher kV for all GOS screens.
Table 2 presents the interpolated basic spatial resolution results for the duplex wire gauge method. The four scintillator screens were tested using the three beam conditions. Resolution below the pixel pitch of the detector was achieved with the DRZ Fine screen. The DRZ Standard screen gave a resolution near or below the pixel pitch, whereas the DRZ Plus screen resulted in a resolution above the pixel pitch. The DRZ High screen had a resolution much higher than the pixel pitch of the detector. In general, the sharpness became worse as the kV was increased.
Table 2: Duplex wire gauge resolution values.

<table>
<thead>
<tr>
<th>Resolution (µm)</th>
<th>RQA5</th>
<th>RQA9</th>
<th>220 kV, 8 mm Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRZ Fine</td>
<td>95</td>
<td>100</td>
<td>105</td>
</tr>
<tr>
<td>DRZ Standard</td>
<td>120</td>
<td>125</td>
<td>130</td>
</tr>
<tr>
<td>DRZ Plus</td>
<td>160</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td>DRZ High</td>
<td>225</td>
<td>225</td>
<td>225</td>
</tr>
</tbody>
</table>

3. Summary

The DRZ Standard GOS scintillator screen was the best choice for NDT applications utilizing the Carestream DRX PLUS digital detector array panel. The choice of the DRZ Standard screen resulted in the best overall image quality above 2 cycles/mm, and it resulted in images that had sharpness that was at or below the pixel pitch of the detector.

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References