Study of Spatial Resolution in LP/cm for FPD Based Digital Radiography System by Imaging the Converging Line Pair at Different Geometric Magnifications

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Abstract

The measure of how closely lines can be resolved in an image is called spatial resolution. Spatial resolution in digital radiography is determined by detector characteristics and by factors includes un-sharpness due to focal spot size of X-Ray tube & geometric magnification of the object of radiography. The modulation is obtained from the difference between the max & min pixel value at each spatial frequency and expressed in the form of Modulation Transfer Function (MTF). In this study, the spatial resolution was measured in Line Pair per centimetre (LP/cm) and MTF was analytically calculated by taking images of Converging Line Pair (CLP) on FPD because the CLP generates square wave of signal similar to bar pattern test object which is one of the methods for the calculation of MTF. The MTF graph was plotted up to the max spatial resolution obtained in the images of CLP taken with two different X-Ray focal spot and at four different geometric magnifications. This paper describes how the geometric magnification affect the spatial resolution measured in LP/cm.

Keywords: Converging Line Pair, FPD, geometric magnification, grey value, MTF, Nyquist frequency, Spatial resolution

1. Introduction

Digital radiography has provided a substitute for conventional film radiography of tubular butt welds in modern “Auto-TIG” production line in power plant equipment manufacturing factories. Benefits of automatic welding are only when then operator gets real time feed-back about weld quality so that welding parameters can be adjusted immediately, thus keeping the rework percentage to a minimum.

In Digital Radiography (DR), the performance of the system can be measured on the basis of modulation transfer function (MTF), which shows obtained contrast in relation with spatial frequency. Generally in digital radiography, the resolution varies with the pixel size of the detector, focal size of the X-Ray tube and X-Ray energy [1]. This study focuses on spatial resolution of the DR system with different focal spot sizes of X-Ray tube and at different geometrical magnifications.

The maximum achievable resolution is the limiting frequency under which a detail can still be recognized on the output device of the imaging system. It can be measured in Line-pairs per centimetre (LP/cm).

The method of calculating MTF by measuring modulation obtained from the difference between the max & min grey value at each spatial frequency up to which aliasing effect is not found on images of CLP.
2. Equipment Details

All the experiments for this study were done at digital radiography system of L&T-MHPS Boilers Pvt. Ltd. Details of FPD is listed in below table (refer Table-1).

<table>
<thead>
<tr>
<th>Table 1 Details of FPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scintillating material</td>
</tr>
<tr>
<td>Photodiodes</td>
</tr>
<tr>
<td>Pixel pitch (p) &amp; size of pixel</td>
</tr>
</tbody>
</table>

According to the sampling theorem, spatial frequency of signal below Nyquist frequency can be faithfully imaged [6]. If the signal contains higher frequencies, then a phenomenon known as aliasing occurs wherein the frequency of the signal beyond the Nyquist frequency is mirrored or folded about that frequency in accordion fashion [2]. The value of Nyquist frequency is $(2p)^{-1}$, where $p$ is the pixel pitch. Therefore according to above discussion, for the detector of 0.2 mm pixel pitch it is not possible to resolve the signal having frequency greater than 2.5 cycles / mm (25 cycles / cm).

A converging line pair IQI (as per ASTM E 2445-05) was used for the experiments is as shown in Fig. 1.

![Fig. 1 Converging Line Pair IQI](image)

3. Experimental Set-Up

The FPD, X-Ray tube & CLP were kept at different distances relative to each other. Table 2 shows the details of approximate geometrical distances of focal spot to FPD distance (D) & focal spot to LP IQI distance (S).

<table>
<thead>
<tr>
<th>Table 2 Details of experimental setups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set up no</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>4</td>
</tr>
</tbody>
</table>

Two exposures were taken for each focal spot for each setups mentioned in table 1. All the exposures were made at 100 kV X-Ray energy.

4. Analysis of Digital Images

Total eight digital images were taken by imaging the CLP by using two focal spots and at four different geometric magnifications obtained due to four different setups mentioned in Table 2.
4.1 Method for MTF Calculation from Line Profile

The line profile was generated for different LP/cm of the image.

As shown in Fig. 3 the line profile has 11 peaks, which represents the high grey value obtained due to 11 slots (gaps) in the body of CLP & 10 valleys represents the low grey value obtained due to 10 metal bridges (ribs) in the CLP body. After certain values of LP/cm, the line profile would not be able to show the 11 peaks & 10 valleys like Fig. 3. So the max spatial frequency resolution is LP/cm up to which the line profile can be obtained as mentioned above.

The grey values of the each peak & valley of the line profile was recorded. The values of each peaks was then averaged to $G_1$ & the values of each valley was averaged to $G_2$. The grey value for the dark background (max pixel value for direct radiation to the FPD) was recorded, that is $G_{max}$. The min grey value of the pixel on the body of the CLP is recorded that is $G_{min}$.

Modulation for each LP/cm is calculated by the following equation (1) [5, 8, 9].

\[
\text{Modulation} = \frac{G_1 - G_2}{G_{max} - G_{min}}
\]

The CLP generates the square wave of contrast signal. The above equation gives the value of the MTF for the sinusoidal wave signal. For square wave signals, the value obtained by above equation should be multiplied by the factor $\pi/4$ as per Coltman formula [4, 7, 9].

![Fig. 3 Example of a line profile](image)

![Fig. 4 M v/s resolution at both focal spots](image)

![Fig. 5 focal spot wise MTF at M=2.32](image)
4.2 Focal Spot Wise Spatial Resolution Comparison

From set up no 1 to set up no 4, as the magnification (M) increases, then max obtained spatial resolution increases for 0.4 mm focus but for 1.0 mm focus first the same increases and then decreases. (Table 3 & Fig. 4). Fig. 5 shows the difference in spatial resolution on MTF curves for digital images taken by both focal spots at max geometric magnification which shows the loss of resolution due to higher blur produced by 1.0 mm focal spot compared to 0.4 mm focal spot. For same LP/cm resolution the obtained modulation is higher for 0.4 mm focus than 1.0 mm focus as shown in MTF curve in Fig. 5. The graph is plotted up to the value of max obtained spatial frequency resolution in LP/cm. Why in set up no 1, the spatial resolution is same with both the focal spot is explained in clause 4.3.

<table>
<thead>
<tr>
<th>Set up no</th>
<th>Measured magnification M</th>
<th>Max possible resolution 25*M [LP/cm]</th>
<th>Resolution with 0.4 mm focus [LP/cm]</th>
<th>Resolution with 1.0 mm focus [LP/cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.07</td>
<td>26.75</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>2</td>
<td>1.35</td>
<td>33.75</td>
<td>33.5</td>
<td>29</td>
</tr>
<tr>
<td>3</td>
<td>1.74</td>
<td>43.5</td>
<td>43</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>2.32</td>
<td>58</td>
<td>48</td>
<td>20</td>
</tr>
</tbody>
</table>

4.3 Effect of Geometric Magnification

As the relative distance between X-Ray focal spot, CLP & FPD are changed, geometric magnification (M) changes. The geometric magnification was calculated by taking the ratio of width of CLP body in image to the actual width. Table 3 shows the values of M for all four setups.

Fig. 6 shows the graph of MTF for Images taken by 1.0 mm focal spot for all four setups. It can be seen that the modulation falls off with increasing spatial frequency. Spatial resolution first increases from setup no 1 to setup no 2 due to geometric magnification (Fig. 4).

![MTF with 1.0 mm focus](image1)

![MTF with 0.4 mm focus](image2)

Fig. 6 MTF with 1.0 mm focus for all setups  
Fig. 7 MTF with 0.4 mm focus for all setups
Setup no 2 can resolve up to 29 LP/cm that is max resolving capability at about 4 % contrast. From setup no 2 to set up no 4, as the magnification increases, the amount of un-sharpness in the system due to 1.0 mm focal spot increases this leads to decrease in spatial resolution & MTF. Fig. 7 shows the graph of MTF for images taken by 0.4 mm focal spot for all four geometric magnifications. Here due to small size of focal spot, the blurring due to focal spot is low compared to 1.0 mm focus at all magnifications. Therefore the MTF & spatial resolution of the system increases continuously in LP/cm for all four setups as the geometric magnification increases though the blur increases with magnification.

The Nyquist frequency for FPD is 25 cycles / cm as per the clause 2. A millimetre of FPD contains 5 pixels i.e. 5 photodiodes. Each signal is in the form of difference in the x-ray intensities reaching the detector after passing through metal bridge (ribs) & gaps (slots) of CLP. Min 2 no of photodiodes are required to read a wave of signal effectively such that one reads the higher value of light corresponding to the higher X-Ray intensity coming from the gap (slot) of the CLP & the other must read lower value of light corresponding to the lower X-Ray intensity coming from the bridge (rib) of the CLP to make it possible to show the contrast in the image by difference in grey value of adjacent pixels. To understand the effect of geometric magnification on the resolution consider two different cases of line profiles generated at 26 LP/cm with 0.4 mm focal spot & geometric magnification of 1.07 (case 1) & 2.32 (case 2).

For first case each pixel on the line profile shows high & low grey values corresponding to the metal Bridge (ribs) & gap (slots) of CLP body as shown in Fig. 8. The signal (X-rays) coming from each line pair of 26 LP/cm area is resolved by two photodiodes of the FPD because the length of signal is about two pixels (corresponding to the two photodiodes). at the plane of FPD. The size of signal coming to the detector is enlarged 1.07 times than the size of the signal wave formed at CLP body. Therefore the frequency of signal at the plane of FPD is 26/1.07 = 24.3 which is less than 25 cycles / cm (Nyquist frequency) and so the FPD would be able to resolve it. For the signal coming from 27 LP/cm, the frequency of signal at FPD will be 25.3 cycles / cm which is higher than Nyquist frequency and so it cannot be resolved by the FPD. Therefore 26 LP/cm is the max possible spatial resolution at geometric magnification of 1.07 with both the focal spot.

Fig. 8 Line profile at 26 LP/cm for M=1.07

Now considering second case in which the each signals (X-Rays) coming from a single line pair is read by four or five photodiodes. (Fig. 9) because here the signal is 2.32 times larger in size than actual signal formed at 26 LP/cm at CLP body. In both the case the spatial frequency of signal at the body of CLP is same but due to higher magnification in setup no 4, the frequency of signal at
FPD is less & equals to \( \frac{26}{2.32} = 11.2 \text{ LP/cm} \) because of larger size of the signal. Therefore the same signal formed at CLP is read by two photodiodes in case 1 & by four or five photodiodes in case 2 (Fig. 10). Therefore in second case still higher spatial frequency signals (more than 26 LP/cm) coming from the CLP body can be read by FPD.

![Fig. 10 size of signals of both cases with respect to pixel pitch of FPD](image)

If the focal spot blurring is not present in the system then by set up no 4 max possible resolution will be 2.32*25 that is 58 LP/cm. But due to focal spot blurring at this magnification, the max resolved spatial frequency is limited to 48 LP/cm.

For setup no 2 & setup no 3 at geometric magnification of 1.35 & 1.74 respectively, with 0.4 mm focal spot, the obtained resolution is up to the maximum possible resolution as shown in Table 3.

5 Conclusions

For any geometric magnification maximum possible resolution in LP/cm will be 25*M, where M is the magnification factor (Table 3) provided the focal spot blurring is not present. But in actual system of digital radiography due to focal spot blurring the max resolution with FPD is 48 LP/mm irrespective of available contrast. If 10 % contrast is considered for limit of resolution then spatial resolution with 0.4 mm focal spot & at max geometric magnification is about 39 LP/cm. This study had opened the door for checking the weld soundness at our site with higher weld image resolution.

References


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