# Digital Radiography for the Inspection of Small Defects

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**Abstract.** Digital Radiography offers several advantages over conventional film-based radiography for NDT applications; the digital detectors typically require much less radiation to create an image. The disadvantage of using digital detectors is the relatively poor resolution in comparison to fine-grain film. The manufacturers of such detectors counter this objection by pointing out that projection magnification can be used to increase the image size, thereby increasing the effective resolution of the final image. This is correct, if a suitable mini or micro-focus generator is used. Unfortunately, these generators tend to be significantly lower in power, so it is essential that the detector be extremely sensitive.

Many manufacturers of digital radiographic inspection units claim that their systems can use projection magnification up to a factor of 100 or more. This may be the case, but the geometric unsharpness (calculated from their own published specifications) would be many times larger than the pixel-pitch, making such high values of projection magnification redundant.

TWI has been working with a consortium of digital radiographic users from across Europe. Our intention is to develop an inspection unit that uses a highly sensitive digital detector that is capable of rivalling fine-grain film in sensitivity, contrast and resolution. The samples used range from 1mm thick magnesium castings to 10mm thick steel welds.

## Introduction

Digital Radiography has several advantages over conventional film-based radiography:

- The digital detectors require less radiation to create an image, typically only 1 to 4% of that normally required for a D7 film
- The image may be stored, emailed or processed on a PC
- Automated defect recognition systems can be used to analyse the image, replacing the subjective assessment of an inspector

The main disadvantages of using digital detectors, is that the resolution is typically lower than fine-grain film; typically 100µm. Projection magnification can be used to increase the image size, thereby increasing the effective resolution of the final image, but several factors must be taken into account for this. For example, the focal spot size of the X-ray generator must be sufficiently small to avoid excessive unsharpness. A micro-focus generator is required for this. Unfortunately, these generators tend to be low in power, so it's essential that the detector is extremely sensitive, and the Source to Detector Distance (SDD) must be kept as low as practically possible.
The objective of this paper is to study the affect of unsharpness and increased image resolution due to projection magnification (PM). It was found that there is an optimum

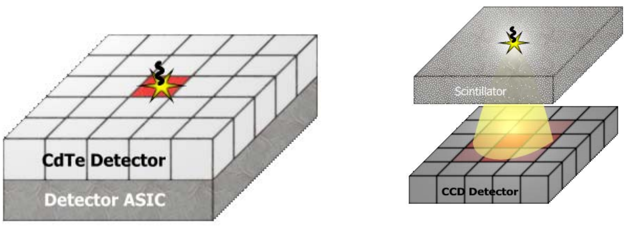
value of projection magnification, which can be calculated from the SDD, measured focal spot size and pixel-pitch of the detector. If too little projection magnification is used, then the image lacks resolution, whereas too much projection magnification will cause excessive geometric unsharpness.

## The Detector

### *Direct-Direct Conversion*

As mentioned in the introduction, it is necessary to use a micro-focus X-ray generator, in order to reduce the amount of unsharpness when using projection magnification. Unfortunately, these sets tend to be low powered, as the finite size of the focal spot limits the amount of X-rays that can be produced without overheating. To overcome this problem, it is essential to use an extremely sensitive detector. If the images are to remain sharp, it is also essential to use a detector with very little inherent unsharpness.
For these reasons the Ajat SCAN300 was selected. This detector is of the direct-direct type, in which X-rays are directly converted into charge, rather than the direct-indirect systems, where X-rays are first converted into light, by way of a scintillator plate. Figure 1 demonstrates the principle of a Cadmium Telluride (CdTe) detector.

Figure 1 Cadmium telluride detector




Direct-direct CdTe detector (left) and an indirect-direct CCDs or TFTs (right)

Figure 2 is a photograph of the detector. It consists of 64 by 1500 pixels at a pixel-pitch of 100µm. This linear detector array is scanned across the image, perpendicular to the array. A frame is captured every 100µm, overlapping the individual frames. Frame accumulation is then used to decrease the noise and increase the number of bits.

Figure 2 The Ajat detector

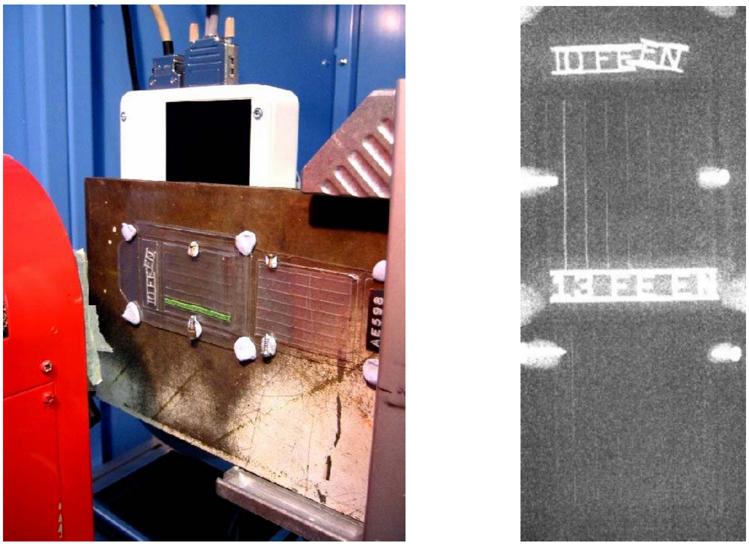

This detector has the following specifications [1,2]:

- Direct conversion of X-rays
- DQE: >90% @ 90kV
- MTF: >80% @2lp/mm; >40% @5lp/mm
- 300 frames per second (frame mode); 80cm/sec (line output mode)
- <1% afterglow @ 3msec after exposure
- Contrast resolution 0.4 to 0.7%

*Sensitivity of the CdTe Detector*

The main advantage of the CdTe detector is its sensitivity when used with low powered micro-focus generators. The radiograph shown below is of a 10mm steel plate, taken with a 75µm micro-focus generator at 150kV and just 0.5mA. The pixel-pitch of the detector was 100µm, but projection magnification was used to increase the image resolution to 43µm. Wire 18 is visible, proving a sensitivity of 0.63%, despite the very low X-ray settings. Obviously the image has been adjusted for brightness and contrast; the image would not normally be this grainy.

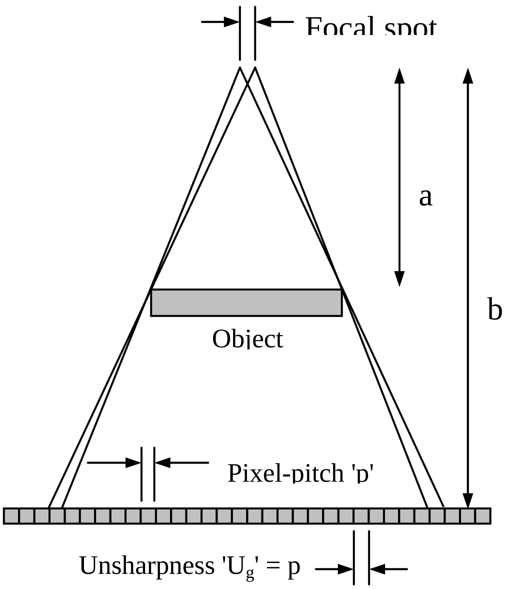
Figure 3 Sensitivity of the CdTe detector



## Projection Magnification

In theory, the optimum value of projection magnification should occur when the value of geometric unsharpness is equal to the pixel-pitch of the detector [3], as shown in Figure 4.

Figure 4 Diagram of projection magnification




It should be noted that a similar condition occurs when using traditional film. In the case of film, the geometric unsharpness is set so that it is equal to the film unsharpness. If the value of projection magnification is larger than this optimum, the image unsharpness will limit the resolution of the final image. If it is smaller than this, the image resolution will be limited by the finite pixel-pitch.

If the Source to Detector Distance (SDD) 'b' is known, along with the pixel-pitch 'p' and the focal spot size 'f', then the source to object distance 'a' can be calculated from the equation below:

Equation 1 $$a = f \frac{b}{(p + f)}$$

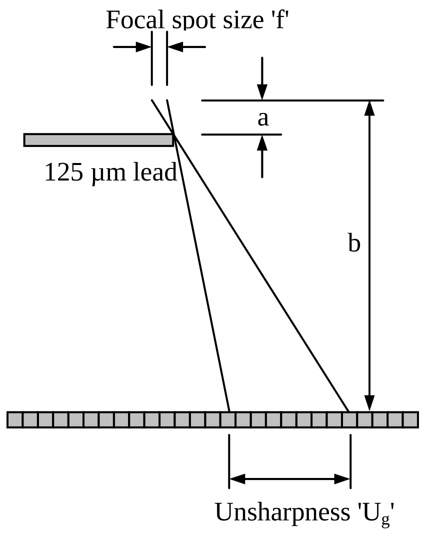
*Measuring the Focal Spot Size*

In order to use Equation 1, it is necessary to measure the focal spot size of the generator in question. The manufactures will declare a value in the specifications, but these values are typically smaller than the experimentally measured values.
To correctly calculate the optimum value of projection magnification, it is necessary to determine the actual focal spot size. This can be done by the following experiment. It should be noted that the generator used in these experiments had a variable focal spot size. The manufacturer gave the following values for focal spot sizes:

- Small: 5µm
- Medium: 20µm
- Large: 50µm

Figure 5 is a diagram of the experimental setup

Figure 5 Measuring the focal spot size

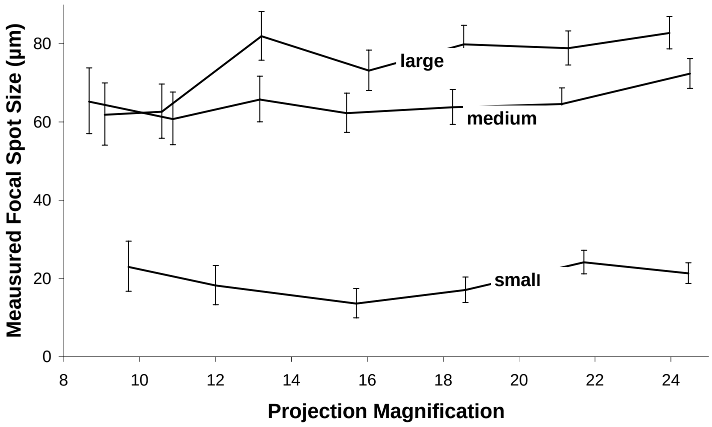



The focal spot size is measured by placing a 125µm lead sheet, with a sharp edge, close to the focal spot, to produce a large amount of unsharpness. The image is captured and the value of $U_g$ obtained for that Source to Object Distance 'a'. The value 'a' is then altered and the value of $U_g$ measured again. This was done for all three focal spot size. The focal spot size can then be calculated from Equation 2, below:

Equation 2 $$f = U_g \frac{a}{b - a}$$

Figure 6 shows the result of this experiment.

Figure 6 Measured focal spot sizes




The averaged results of this experiment was that the measured focal spot sizes were:

- Small: 20µm
- Medium: 65µm
- Large: 75µm

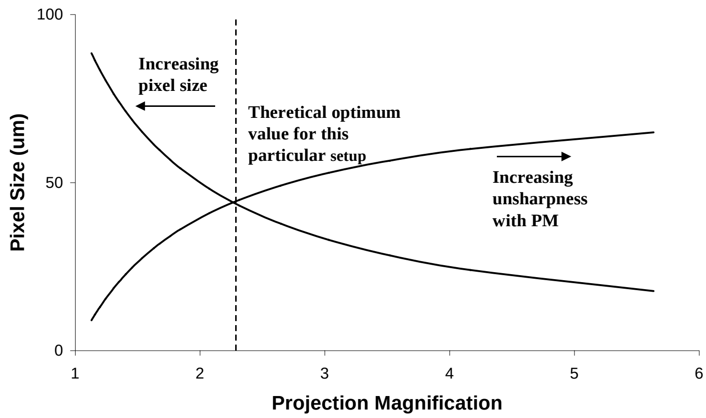
*Pixel-pitch / Unsharpness Matching*

Once the actual focal spot size is known, Equation 1 can be used to calculate the ideal value for the Source to Object distance 'a'. The optimum value of Projection Magnification (PM) can be calculated from Equation 3, below:

Equation 3 $$PM = \frac{b}{a}$$

If too little projection magnification is used, then the resolution of the final image is limited by the pixel-pitch of the detector; if too much projection magnification is used, then the image will suffer from too much unsharpness. Figure 7 demonstrates this principle.
The first solid line shows how the final image pixel size decreases with projection magnification. The second solid line shows how the geometric unsharpness increases with projection magnification. The optimum resolution of the final image occurs where the two solid lines cross.

Figure 7 Optimum value of projection magnification

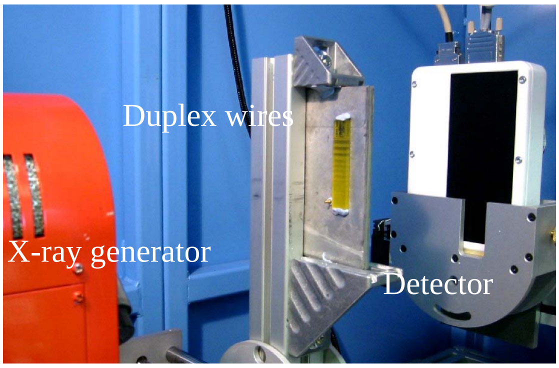



This shows that there is little or no point in over magnifying the image too much. Over magnification unnecessarily increases the file size, and decreases the effective imaging size of the detector, without revealing any more detail.

*Experiment in Projection Magnification*

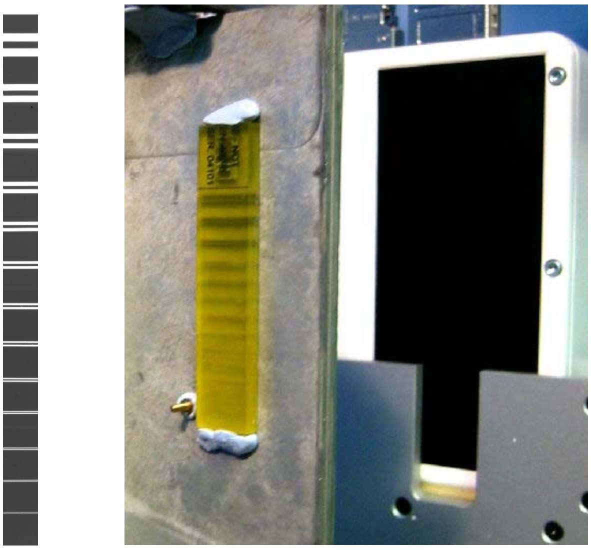
In order to prove the theory of an optimum value of projection magnification, duplex wires were used to measure the unsharpness of a series of images over a wide range of projection magnification values.  Figure 8 and Figure 9 show the experimental setup.

Figure 8     Experimental setup



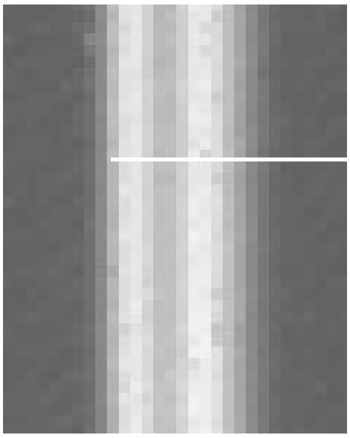

The duplex wire is one of the standard radiographic techniques used to measure unsharpness.  Unfortunately, for this experiment, the smallest wires were always resolved, due to the small focal spot size of the generator.

Figure 9     Experimental detail



To overcome this problem, the profile was measured across the smallest wire pair.

Figure 10   Radiograph of the smallest wire pair



Line profile measured across smallest wire pair

The greyscale value was plotted against distance, to produce the familiar profile shown in Figure 11 below:

Figure 11   Typical line profile across a wire pair

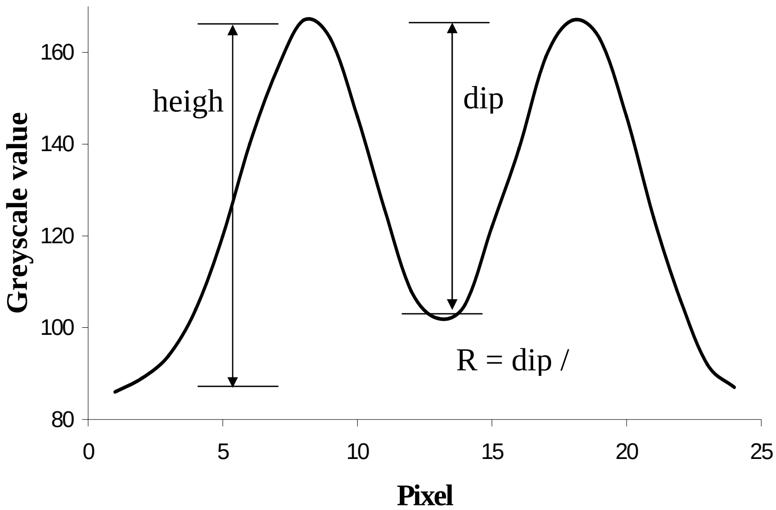
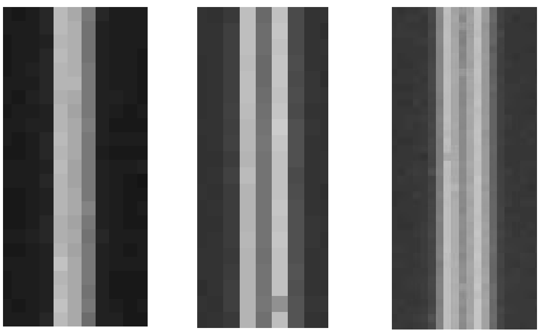



Figure 12 shows three examples of radiographs of wire pairs.

Figure 12   Examples of wire pairs



Too little PM. Wire pairs are not resolved

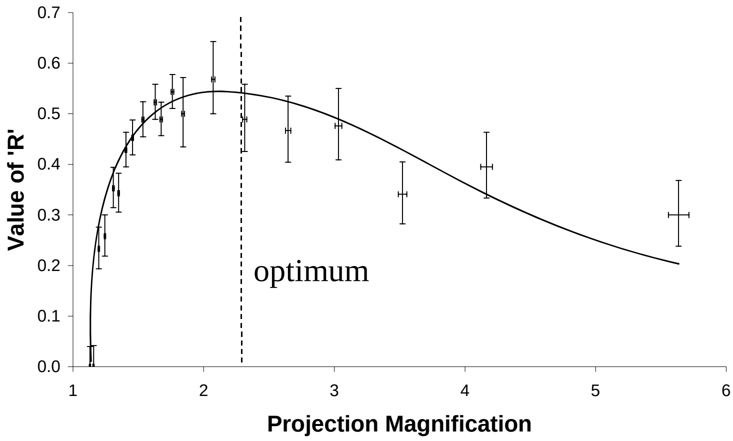
Optimum value of PM. Wires are clearly resolved

Too much PM. Unsharpness has caused the wire pairs to merge

In the first example, very little projection magnification was used. The lack of image resolution has prevented the wire pairs from being resolved; this would give a low value of 'R', as defined in Figure 11. In the second example, the optimum value of projection magnification has been used. The wire pairs are correctly resolved, with a clear 'dip' between them. This would have a large value of 'R'. The final example has too much projection magnification. This has caused an excessive amount of unsharpness to blur the image, leading to a lower value of 'R'.

Figure 13 shows the result of this experiment. For this particular experimental setup, the optimum value of projection magnification was calculated to be 2.3. When lesser values of projection magnification are used, the line pairs are not clearly defined, as shown in Figure 12, and the value of 'R' is low. Closer to the ideal value of projection magnification, the value of 'R' increases, as the wire pairs become resolved. This value of 'R' then decreases as too much projection magnification is used, and the image is blurred by excessive unsharpness.

Figure 13 Value of 'R' against Projection Magnification




## Conclusion

The result shown in Figure 13 proves that the ideal amount of projection magnification occurs when the value of unsharpness is equal to the pixel-pitch of the detector.
In order to image small defects the following points should be considered:

- The use of a microfocus X-ray generator should be used to allow projection magnification to be used to overcome the poor resolution of flat panel detectors
- Obviously the orientation of the sample is important
- When using a micro-focus X-ray generator, it is important to use an extremely sensitive detector, as the generator will not be able to produce large amounts of radiation.
- It is important to optimise the amount of projection magnification, by matching the geometric unsharpness with the pixel-pitch.

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| | |
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**References**

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