

Realization and application of simulation technology in Direct Radiography

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Abstract

When x-ray penetrates through objects, its energy will be attenuated and the attenuation rate depends on the distance that the ray passed. Computer simulation technology was realized and applied in radiographic testing according to this principle. The simulation process comprises 4 steps: modeling of the workpiece, setting of the layout of the testing, calculating of the distance that the ray passed, quantifying of the distance to obtain simulation image. Then, the quantification method of the depth (or height) of defects in direct radiography (DR) with x-ray linear array detector was studied by simulation technology, and the parameters affecting the result and feasibility of the testing method were analyzed subsequently. Finally, computerized tomography (CT) was simulated to study tomographic reconstruction algorithm, and how to upgrade DR to CT was discussed.

Keywords: Direct radiography, Computer simulation, Defects depth quantification, X-ray linear array detector

1. Introduction

The length and width of defects are easy to measure while the height or depth is difficult to quantify in radiographic testing (RT), for the image obtained is 2-Dimensional. However, 3-Dimensional quantification of the defects is necessary to estimate the service life and workability of the testing object. The depth of defects is easy to calculate by ultrasonic testing; however this method is not suitable for certain material or structure. As RT is widely used, it is valuable to study quantification method of the depth or height of defects. Parallax method is often used to calculate the depth according to the defect displacement in 2 or more images obtained from different position.

Recent years, RT developed quickly, and the recording media progressively transformed from traditional films to digital images^[1]. The digital RT methods include film digitization, real-time radioscopy, computed radiography (CR), direct digital radiography (DR). Each method has its own advantages and should be used according to practical usage. Compared with other record media such as CCD, amorphous silicon or selenium panels, complementary metal oxide silicon (CMOS) has its advantages: higher precision, and more adaptability to temperature and test structure. So, DR system with CMOS array detector is chosen to achieve better testing images and higher efficiency. The detector is used to replace CCD in radioscopy, and mostly substitute traditional films. The parameters of the detector are:

320mm action area, 20Kv-320Kv operational range, 80 micron spatial resolution, 6 Lp/mm without geometric magnification, and 4096 grayscale.

The DR system has multi-axis motion control device, through which to achieve layout desired and relative motion needed in testing: the workpiece placed on the work table can get relative translation or rotation, the x-ray source and the detector can be controlled synchronously or separately to move up and down or adjust their obliquity. The testing parameters in DR can be precisely controlled by NC programs, besides the spatial resolution of DR is high enough, so it opens up prospects for quantification of the defects depth using DR system. Based on the simulation technology, how to quantify the depth of defects in DR was studied in the paper, and the element space of detector was set around 0.08mm.

2. Simulation technology realization^[2,3]

2.1 Simplification of X-ray attenuation rate

The attenuation rate when x-rays penetrate through the workpiece can be described by the equation bellow:

$$N(E) = N_0(E)\Delta\Omega \prod_i \exp(-\mu_i(E)x_i) = N_0(E)\Delta\Omega \exp[\sum_i -\mu_i(E)x_i] \quad (1)$$

Where, $N(E)$ ——photons number that penetrated through the workpiece

$N_0(E)$ ——photons number of x-rays per penetration angle with energy E

$\Delta\Omega$ ——penetration angle of x-rays

$\mu_i(E)$ ——linear absorption coefficient of material i with x-ray energy E

x_i ——distance that x-rays passed through material i

Actually, the focal spot of x-ray source is some kind of size, besides there are random scattered rays in DR. To simplify the simulation, the x-ray spot is idealized to a single point, and the scattered rays effecting test image are ignored. So, the attenuation rule may be simplified by the equation bellow:

$$N(E) = N_0(E)\exp(-\mu(E)x) \quad (2)$$

After calculation of the distance x that x-rays passed, we can obtain simulated DR image by the equation above.

2.2 Modeling of the workpiece

To describe the defects in the workpiece, 3-D CAD model is needed to be established.

The CAD software such as UG、ProE can be used, here UG 4 was adopted.

2.3 Arrangement of the testing layout

The image obtained is affected by the testing layout, so it is necessary to set appropriate parameters, such as the distance between source and workpiece, the distance between workpiece and detector, the relative position that define offset and angle between source and workpiece. In addition, the imaging parameters such as dimension, pixel size are also needed to set.

UG/Open Grip was used to set the testing layout, as shown in fig 1.

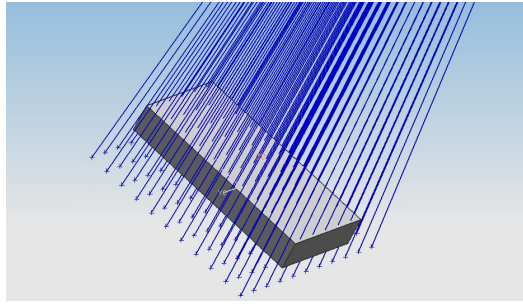


Fig1. Model of DR with UG4

2.4 Calculation of the distances that x-rays passed

Ray-tracing technology was used to calculate the distance that x-rays passed through. UG Open C API was used to make a dll file, which can be called by grip program.

2.5 Conversion of the distances

The Grip program was executed in UG environment, and ray-passing distances from source to every point on the image were calculated. According to equation (2), the distances were converted to energy then digitized to digital image.

3. Quantification of defect depth in DR

3.1 Quantification of porosity defect

3.1.1 Principle

The source was moved to position 1 to get an image and then get another image at position 2 after horizontal movement S , while the recording media was kept still. The depth of the defect can be calculated by triangle relation ^[4].

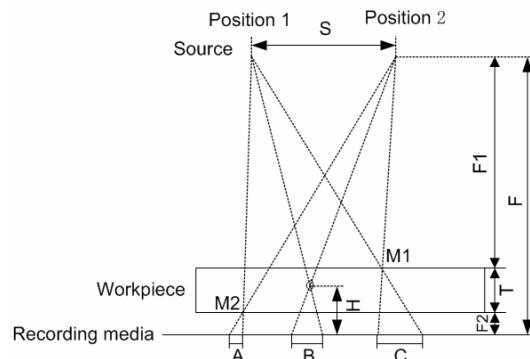


Fig2. Principle to calculate defect depth

$$H = \frac{B \times F}{S + B} \quad (3)$$

Where, H—distance between defect and recording media

S—horizontal movement of the source

B—movement of the defect image

F1—distance from source to upper surface of workpiece

F2—distance from recording media to lower surface of workpiece

T—thickness of workpiece

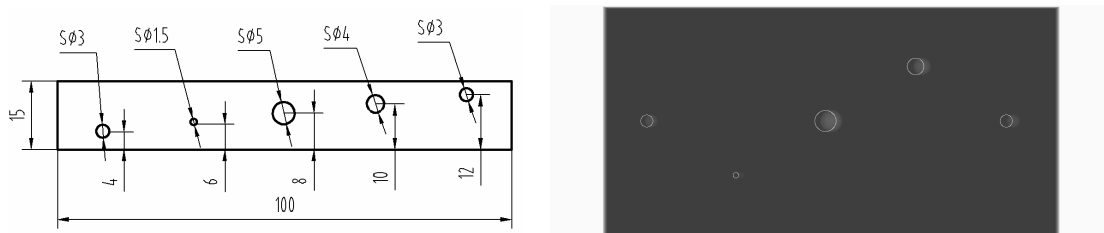
F—distance from source to recording media, $F=F1+F2+T$

If traditional film RT was adopted, the same film needed to expose twice, which would introduce fog into the image. If the defect image was not clear enough, it would need two films and to expose with labels M1 and M2; and then the films were overlapped over the

view box to measure B. When DR is adopted, we can easily get two images needed only by moving the workpiece horizontally without image degeneration, and the NC controlled precision of S is higher than that manually do. Compared with film radiography, DR is more suitable to calculate the defect depth.

3.1.2 Simulation

The workpiece to be inspected is shown in fig 3 a; it has 5 holes with different diameters and depth. In the simulation, F was 700mm, F2 was 10mm, and the element spacing was 0.1mm, the dimension of image was 150 mm×60mm. The source was moved to 4 different positions with 50mm gap from centre of workpiece.

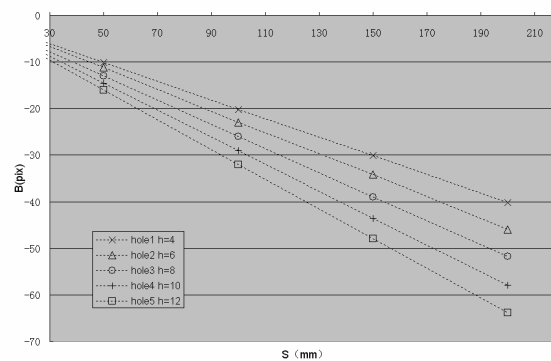


a. Workpiece to be inspected b. Simulated image overlapped(S=50mm)

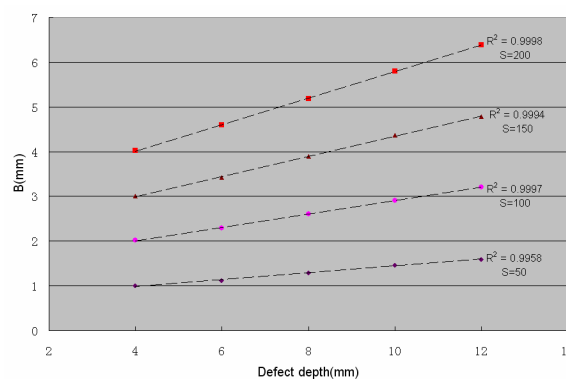
Fig3. Workpiece and simulated image

3.1.3 Analysis

The position of defects will change when source is moved by certain S; the simulated image is shown in fig3 b. The center position of defects can be calculated by image processing technology, and then B can be calculated. With increasing of S, B will increase linearly; the rate of increase relies on the depth of defects, as shown in Fig 4 a.



a) Calculated B with different S



b) Calculated B with different depth of defects

Fig4. Data to quantify defect depth from simulated image

From equation 3, the defect depth can be calculated, and the results are shown in table 1. As hole 2 is small, the result has bigger errors than others. But if the element spacing is changed to a smaller value, the result would be more accurate.

Table 1: Calculated result of defect depth (mm)

S	Hole 1	Hole 2	Hole 3	Hole 4	Hole 5
50	4.021189	5.519328	7.913056	10.06827	11.96128
100	4.03256	5.917849	8.010188	10.0352	12.0355
150	3.969184	5.832571	7.976914	10.06604	11.9635
200	3.998902	5.94137	7.920027	9.999436	11.97317

From equation 3, calculated H affected by many parameters measured. The actual defect depth is H-F2; the calculation is not suitable for practice use, as F2 is not easy to measure with sufficient precision. But from Fig 4 b, we know that B has linear relationship with defect depth. Then we can quantify defect depth by this relationship. This method only needs the linear relationship (add labels M1, M2 to expose at the same time), so it can be used in practice easily.

3.2 Quantification of plane defect

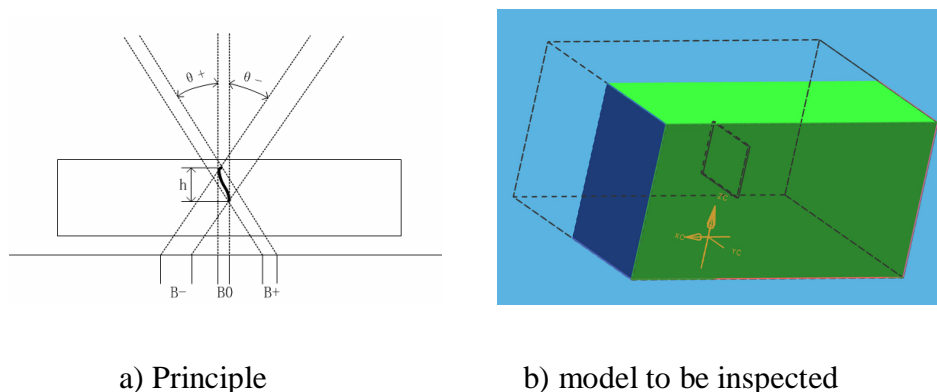


Fig5. Quantification of plane defect

When height of plane defects is to be quantified, it need to change the centre position of the source by rotating certain angle, as shown in fig 5a. The height h can be calculated by the defect movement B in the image:

$$h = (B_+ + B_0)ctg\theta = (B_- - B_0)ctg\theta \quad (4)$$

Model with a plane defect (fig 5b) inside was established, the length, width and height of defect was 6mm, 0.2mm, 5mm separately. When the resolution was 0.05mm, the source was rotated 5 degrees, then the defect movement B was 7 pixels, and calculated h was 4.02mm; if the source was rotated 10 degrees, B was 16 pixels, h was 4.61mm. To improve precision of result, the resolution was changed to 0.02mm, and then calculated h was 4.82mm and 4.83mm correspondingly.

The height quantification result is affected by spatial resolution, image contrast, but the quantification method can be applied in practice easily, for the method only need to change the rotation angle when exposed. In DR system, the source and detector are kept still while workpiece are rotated on the work table, which can be achieved easily and has enough precision by NC program.

4. Computerized tomography of Defect with DR

As mentioned above, multi-angle projection method can be used to quantify the height of plane defects, furthermore it can be extended to Computerized tomography (CT)^[5,6].

The workpiece was placed on the work table and kept rotating, and then the image was acquired line by line for 360 degree. The image was rearranged according to the scan speed, testing layout parameters. After reconstruction, section of workpiece can be got (Fig 6).

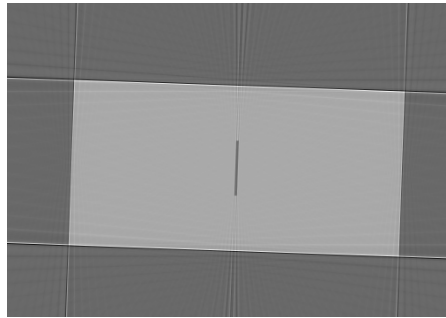


Fig6. CT Image simulated

5. Conclusion

- 1) 3-D Quantification of defect is helpful to evaluate the service life and workability of the testing object. It showed that DR system has more advantages to quantify the defect by parallax method .
- 2) Some simplifications were made to X-ray attenuation rule. UG 4 was adopted in modeling of the workpiece; Open Grip and C API were also used. This offered a simply way to realize simulation in DR.
- 3) Based on simulation technology and characteristic of DR system, the quantification of depth/height of defect was studied. The results showed that quantification could be done with enough precision by image processing technology and NC movement controlled system. As long as tomographic reconstruction algorithm was adopted properly, the DR system could be upgraded to CT system to achieve more accurate result.

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