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Ray Detection Digital Image Quality and Influential Factors

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Abstract: The main index of X-ray real time imaging detection image quality is detection sensitivity, detection sensitivity is relative with image definition, contrast and pixel, and the above factors are related with different technique factors; it can benefit the detection image quality to improve the configuration of system, improve the image dynamic range, drop the image noise, decrease the influence of scatter and filter hard ray.

Key Words: ray detection, digital image, quality, influential factors

1. Image sensitivity and influential factors

The carrier of ray digital imaging detection result is digital image, and the image quality after processed with computer can reach the ray film photographing negative quality. The important index for measuring the digital image quality is sensitivity. image sensitivity refers to the ability to find fine image on the image, value of quantity is the identifiable minimum defect size or minimum detail size on the image; image sensitivity is measured with image quality indicator. China applies metal wire image quality indicator, and the sensitivity obtained from this method is named as image quality indicator sensitivity, although it isn't equal to the natural defect sensitivity, it can actually show the ability of finding natural defect.

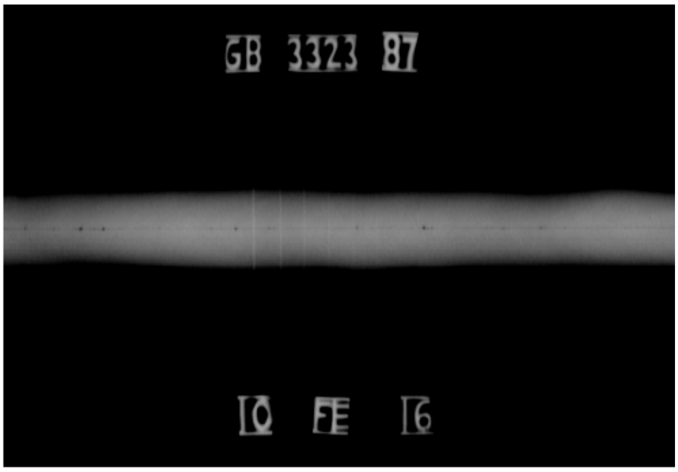

Diagram 1 Steel wire image quality indicator measures welding gap detection image quality (negative)

Ray detection digital image sensitivity is related with image contrast, unsharpness and pixel value, and the factors are related with different technique factors respectively.

2. Image contrast

Image contrast shows the differences of gray scale in neighboring area, and is the important reference for identifying image, if there's thickness difference on the workpiece or there's discontinuity (defect) which has different density with the base material in the workpiece, after detecting the workpiece with ray, in the detection image, defective image and surrounding backgroup has different gray scale, which is the contrast of detection image, contrast can easily show defect. In order to find the small defect and obtain high sensitivity, it shall improve the image contrast.

2.1 Talk from film contrast

Digital imaging detection and film photographing has same ray radiography workpiece principle, therefore, the influential factors of contrast can be analyzed with the ray film photographing contrast formula:

$$\Delta D = 0.4.34 G \mu \Delta T / (1 + n)$$

In the formula: ΔD --- negative density difference (the same as image obtaining difference);

G --- film density average grads (the same as image gray scale average grads);

ΔT --- workpiece thickness difference (the same as X-ray radiography downward defect size);

n --- scattering ratio;

μ --- material line attenuation coefficient (vary inversely with ray tube voltage).

Briefly: Under the condition to penetrating through the workpiece, drop the X-ray tube voltage, or take various shielding measures to improve the image contrast, it also benefits for finding fine defect to improve the contrast.

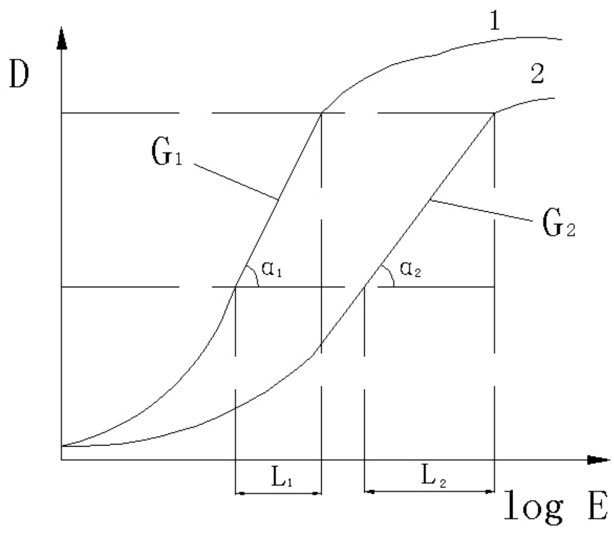

Diagram 2   Film property curve and tolerance

(1) Tolerance (L)

Tolerance means the corresponding exposure (E) range of film effective density (D) range.

Exposure E=mAt(tube current * exposure time);

Film average grads: $G=tg\alpha$;

It can be seen from Diagram 2, $\alpha_1>\alpha\alpha_2$; then $G_1>G_2$, $L_1<L_2$. It shows: under certain density, film which has high grads has low tolerance.

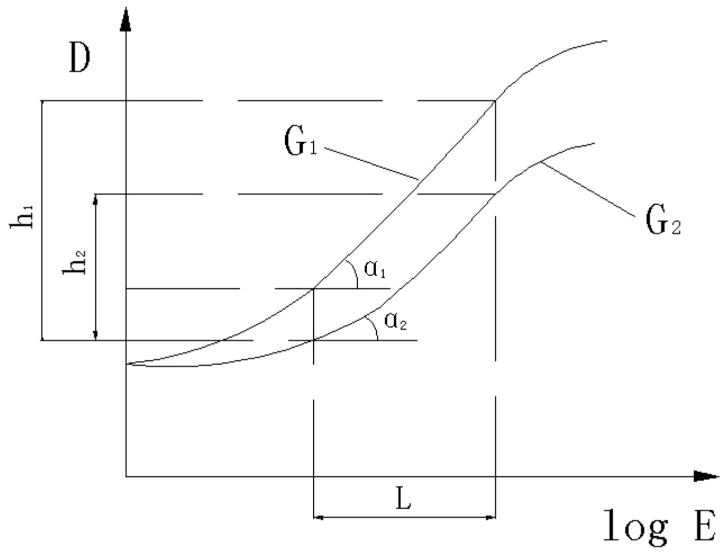

Diagram 3 film property curve and dynamic range

(2) Dynamic range (H)

It can be seen from Diagram 3, under certain exposure range (L), since $G_1>G_2$, then $h_1>h_2$. It shows: under certain exposure, film which has high grads has dynamic range.

2.2 Image contrast

In ray digital detection, the displayed image is black/white, and gray is between black/white. The light and shade of some point in the image (pixel) is called as gray scale (H). The range of image gray scale is called as “grade”, and is calculated from A/D converting and capture card or direct image detector. For example, capture card or image detector is 8-bit ($8bit=2^8=256$), supposed that it is 0 grade when image is full white, and 255 grade when it is full black, then the dynamic range of the image is 256 grade. Gray scale is between black/white. Actually, it doesn’t benefit our observation if the image is too white or too black, and the effective gray scale is mostly controlled at certain range, and this range is named as dynamic range. For example, control the gray scale range <80%, then the upper and lower limit of image gray scale is 25.6 and 230.4 gray scale respectively, the dynamic range is 205 gray scale.

As the improvement of the functions of image capture card or image detector, the image gray scale (bit) is also increasing, currently, it can reach 10bit(2^{10}=1024), 12bit(2^{12}=4096), 16bit(2^{16}=65536). If the gray scale is still controlled within 80%, then the image dynamic range is 819, 3276, 52428 gray scale respectively. The higher the image dynamic range, the clearer and finer the bright layer of the image, the easier the identification of fine defect, and the higher the detection sensitivity. The improvement of image (gray scale) dynamic range is mainly from the improvement of the function of image capture card or image detector, although the price is also increasing, but the cost performance improves fast.

What shall be pointed out is that the ray intensity has dropped powerfully after ray has penetrated through the workpiece, it requires a relatively long time for film exposal, film exposal is the time integral process, but it requires very short time ((1/10 S- 1/25 S) for ray digital imaging to capture one image, image capture is the time differential process. Therefore, image capture mainly focuses on the ray intensity (mA), and the exposure time is not taken into consideration since it is very short, in ray digital imaging detection, only the dynamic range instead of tolerance is taken into consideration.

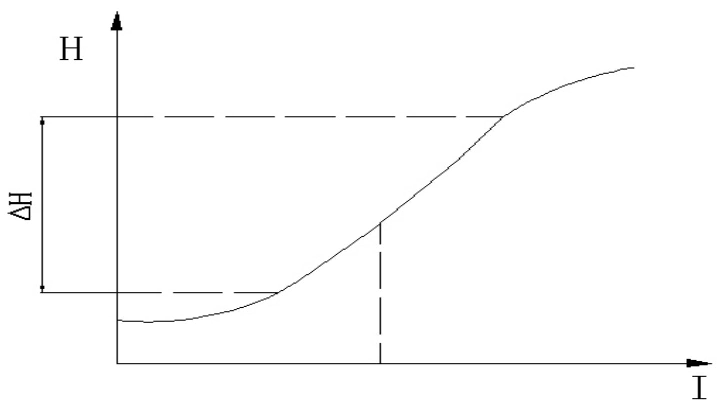

Diagram 4　　Exposure and image dynamic range

When penetrate through thick workpiece or workpiece with high thickness difference, apply image detector which has high digit (for example 16bit), when the ray energy (tube voltage) keeps unchanged, apply high ray intensity (mA) for radiography to obtain different ranges of defects, which is the obvious advantage of ray digital imaging detection.

3. Image unsharpness

Viewing from the image quality, it requires pursuing high definition of image. In order to make calculation convenient, the extended concept is image unsharpness which is opposite with the image definition, it refers to the width of the image edge gray scale transition region (U). image unsharpness is related with geometric unsharpness ($U_{g)}$) , system unsharpness (U_i) and moving unsharpness (U_f). According to the imaging principle, their relation is not the simple arithmetical sum relation but the sum of square or sum of cube relation. When the detection workpiece and image detector are fixed, moving unsharpness (U_f) is 0, and then, their relation formula is:

$$U^3 = U_g^3 + U_i^3$$

3. 1 System unsharpness (U_i)

System unsharpness (U_i) is decided by the system components. X ray digital imaging system mainly composes of X-ray machine, image detector, PC, image capture card, detection industrial equipments and system software. After confirming the system, the system unsharpness is also confirmed, therefore, system unsharpness is objective or immanent.

In X-ray real time imaging detection, image detector (image booster or line array detector or panel detector) can't tightly attach the workpiece, therefore, the detection image shall be amplified, shown in the diagram below.

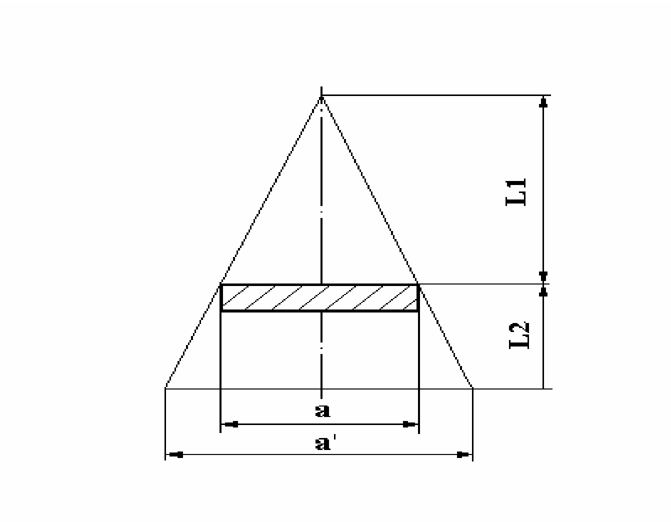

Diagram 5　　Image amplifying principle Diagram

When X-ray source focus size is very small, image amplifying multiple M is:

$$M = \frac{L_1 + L_2}{L_1} = 1 + \frac{L_2}{L_1}$$

In the formula:

L_1 ------- Distance between the ray source to workpiece surface

L_2 ------　Distance between the workpiece surface to image detector surface.

3. 2 Geometric unsharpness (U_g)

Geometric unsharpness (U_g) is only relative with the geometric size of radiography:

$$U_g = \frac{dL_2}{L_1} = d(M-1)$$

3. 3 Functions of image amplifying

It is shown from the experiment result, after amplifying the image, the image unsharpness will drop, which may benefit to detect detail size of the image. The effective definition after amplifying is:

$$U_0 = \frac{U}{M}$$

U_0 --- determine the effective unsharpness of the image detail minimum detective size

However, with the influence of geometric unsharpness, it not means the better the higher the image amplifying multiple is. From the differential equation, obtain the best amplifying multiple Mopt:

$$M_{opt} = 1 + \left(\frac{U_i}{d}\right)^{3/2}$$

Generally speaking, when confirming detection technique, the technique amplifying multiple M=Mopt shall be taken.

3. 4 Minimum defect size

Under best amplifying multiple, the minimum defect size d_{min} which can be detected by the imaging system is:

$$d_{\min} = \frac{U_i}{M^{2/3}}$$

3. 5 Test of unsharpness

The system immanent unsharpness and image unsharpness can be objectively tested with image resolution test card.

4. Pixel

Pixel is the minimum unit of image. Image composes of several even horizontal lines, every line has several pixels, and is the basic element for the displaying quality of the image. For 17” display, the pixel arrangement is 1600×1280, it means it has 2M pixel, the more the pixel, the clearer the image.

4. 1 Apply display with high definition and high brightness

As the development of technology, it is the trend of displaying technology development to replace traditional display with LCD, since digital imaging detection image is gray scale image, in order to improve the image displaying quality, in the ray digital imaging detection system, it is better to apply gray scale display with high definition and high brightness. For example:

2M:1600×1200, 2 million pixel, applicable for displaying CT image.

3M:2048×1536, 3 million pixel, applicable for displaying digital DR,CR image

5M:2560×2048, 5 million pixel, applicable for displaying image with higher resolution .

4. 2 Image detector with relatively high pixel

Image booster: the chip pixel of CCD vidicon which is used in the past industrial detection is low, and is only 768×576, and 400,000 pixel, which has influenced the improvement of image definition, as the development of CCD technology, currently, 1M(1024×1024) and 2M(1600×1200) CCD vidicon has been developed for industrial detection, match with LCD of high definition, the image quality is powerfully improved.

Line array detector and panel detector itself has relatively high pixel and can obtain relatively high image quality.

5. Resolution

Definition means the degree of the fine line in the image which can be identified by human eyes. It is shown with the spacing between to lines, the line spacing is wide, then the image is clear, line spacing is narrow, it means the image is not clear.

In ray film photographing detection, the carrier of detection result is negative, the basic unit of negative image is silver salt granules. The black metal silver granule generated from the single light sensitive granule developing do not exceed 0.01mm, or even lower, which is much lower than the identifying limit for human eyes, therefore, negative clearness is very important. However, in ray digital imaging detection, the basic unit of image is pixel, and pixel is shown with spacing, the lower the spacing is, the more pixels are in certain width, generally speaking, the spacing of display is 0.28, 0.25, 0.21mm, or lower spacing, but it doesn’t be lower than 0.1mm, therefore, in ray digital imaging detection, the ability of identifying fine size or fine defect (named as “resolution”) is the important factor for the image quality. The identifying ability in unit range is named as resolution.

Resolution is the complicated concept in imaging, in ray digital imaging detection, the unit of resolution is line pairs /mm (LP/mm), line pairs compose of two lines, the gap between the lines equals the width of line. Image resolution can be objectively tested with resolution test card (or other test tools). Diagram below is a kind of typical resolution test card.

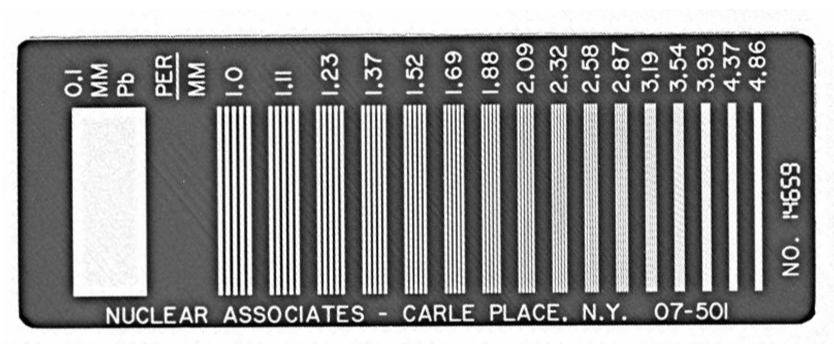

Diagram 6 Resolution test card

5.1 Conversion relation of resolution and definition

Viewing from the definition, although image definition and image resolution have different focuses, they are used for identifying the clearness and identifying ability of image with same essence, therefore, it is “two explanations of one issue”, or “two aspects of one issue”, and there’s one conversion relation between them. Resolution can be objectively tested with resolution test card, and the unit is LP/mm. The corresponding relation of image definition and image resolution is “half of mutual reciprocal”, the unit of image definition (or unsharpness) is mm. It can perfectly solving the problem of calculating definition (or unsharpness) and best amplifying multiple with the conversion relation. (Please see the JB/T 10815-2007 “identifying ability test for nondestructive detection ray radiograph detection” standard for the structure and calculation of definition of the resolution test card.)

5.2 Regulations on related resolution indices

Chinese constituted (modified) standards on system resolution and image resolution have regulated the ray digital imaging detection:

The resolution of imaging system and image detection shall ≥3.0 LP/mm.

6 SNR

SNR occurs with the noise when the imaging system works. The simple definition of “Noise” is: “signal generated from the equipment during the processing course”, noise signal is not relative with input (or output) detection signal.

SNR: ratio of output max signal and output noise signal, the unit is db. image SNR shall not be lower than 65dB.

It can benefit to improve the image quality to improve SNR. Methods of improving SNR: (1) improve the image dynamic range, improve the gray scale of image pixel. (2) drop the noise signal.

Image pixel mean square difference σ can show image noise:

$$\sigma = \sqrt{\sum_{i=1}^{n} (P_i - \overline{P})}$$

$$\overline{P} = \frac{1}{n} \sum_{i=1}^{n} P_i$$

In the formula:

σ --- Image pixel mean square difference;

n --- Total pixels in the total measuring range;

P_i --- Pixels in the total measuring range;

$\overline{P}$ --- Average pixel in the total measuring range.

7. Methods for improving image quality

The methods for improving the image quality: increase exposure, improve the image dynamic range, drop the image noise, decrease the scatter and filter hard ray.

It can effectively drop the influences of the scatter to image quality by applying raster beam limiting and blocking methods.

Apply metal foil which has high density (for example: copper foil) to filter hard ray.

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