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Study on the density characterization of the CT image

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Abstract

This article introduced the attenuation rules of the broad beam and continuous spectrum X-ray that was passed throughout the simple substance or mixture substance. The CT values in the CT image were in proportion approximately with the density of its object. A series of affected factors on CT values were given. After analyzing the test result data, it was educed that, when the structure substance was fixed on, the change was only on the dynamic range of the testing data, but not on the relation curve shape between the CT values and substance density. It was useful thing to converse working.

Key words: Industrial Computed Tomograph (ICT), NDT, Converse working，Density

1. Introduction

The technical of Industrial Computed Tomograph (ICT) has been wildly used to nondestructive test (NDT) and nondestructive evaluation (NDE) for various products. This kind of technical been not limited on if the product was conducted the magnetic or electric and there were holes in it. Especially for the multi-materials structure, the test not only gave out the image message of the scanning section, but also the CT values could be down the statistic and measure to each material.

Along with the technical development of the ICT converse working, it is not only to measuring the shape size and location size interior structure on ICT scanning image, but also to measuring the CT values of any spots or regions on the image. The values of CT in its image were showed in different gray scale. The CT values in the CT image were in proportion approximately with the density of its object. It was a useful thing to judge the density with the value of the CT for converse working [1]. Follow was the researching discussion of the technique.

2. The attenuation rules of the board beam and continuous spectrum X-ray

When X-ray passed through something, it obeyed a certain attenuation rule. Known from the reference [2], the strength of the penetrated X-ray is equal to the sum of the strength of the primary passed X-ray and the dissipated passed X-ray, namly

$$I = I_D + I_S \qquad (1)$$

In this formula I…the strength of the penetrated X-ray；

I_D…the strength of the primary passed X-ray；

I_S…the strength of the dissipated passed X-ray

When X-ray is single color and narrow beam, the attenuation rule of the penetrated X-ray is

$$I_D = I_0 e^{-\mu T} \qquad (2)$$

In this formula I_0…the strength of the single color X-ray before penetrating；

μ… linear attenuation factor，unit as cm^{-1}；

T… the passed through thickness of the X-ray

It was always introduced the dissipating ratio n for dissipated X-ray,

$$n = I_S / I_D$$

Hence we have

$$I = I_D + I_S = (1+n) I_0 e^{-\mu T} \qquad (3)$$

From the researching of experiment, to normal energy and object within limit of the absorb of X-ray, there is

$$\mu_m = \mu/\rho = kZ^3\lambda^3 \qquad (4)$$

In this formula μ_m…quality attenuation factor;

ρ…the density of substance；

k…factor；

Z…the atomic number of the substance；

λ…the wavelength of the incident X-ray

The formula expressed the relationship of the quality attenuation factor and the atomic number of the substance and the energy of the X-ray in the concrete. For certain object, the attenuation factor is not same for the different energy X-ray. The attenuation factor is not same for the different object yet when certain energy X-ray passed through it. For certain X-ray energy, the bigger the atomic number, the more density of the substance, the more attenuation the X-ray within it. For different X-ray energy, the lower energy X-ray has more attenuation within same substance.

When object was a mixture, if its elements percent that it were made up of were W_1, W_2, W_3,…, its each quality attenuation factors were μ_1, μ_2, μ_3,…, the object's quality attenuation factor was

$$\mu_m = W_1\mu_{m1} + W_2\mu_{m2} + W_3\mu_{m3} + \ldots \qquad (5)$$

In assume of reconstruct theory of CT image, projecting data was in direct proportion with the linear integral of the attenuation factors along the projection direction. Because the X-ray used in ICT was the continue spectrum X-ray, it was need to consider the attenuation rule of the continue spectrum X-ray. Due to the attenuation that the different energy X-ray passed through the same thickness substances was not same, it was always introduced a theory equivalent wavelength in analyzing continue spectrum X-ray. The half value thickness to the equivalent wavelength must be the same with the half value thickness of the continue spectrum X-ray.

A strict treating was very complex to broad beam and continue spectrum X-ray. If let the linear attenuation factor μ in formula (3) be the linear attenuation factor of the equivalent wavelength, the formula (3) could be used in the attenuation rule of broad beam and continue spectrum X-ray approximately.

In addition to the same continue spectrum X-ray, the different passed through thickness was not corresponding the same equivalent wavelength. Along with the increasing the thickness that passed through, the equivalent energy of the transmission X-ray, such as equivalent wavelength was become “harder” compared with incident X-ray. That was to say the equivalent energy increasing.

3. The relation between the CT values and the density

Coming from the former analyzing, the relation between the strength of the penetrated X-ray and the substance density could be write as

$$I=(1+n)I_0e^{-\mu T}=(1+n)I_0e^{-\rho\mu_m T}=(1+n)I_0e^{-\rho k Z^3\lambda^3 T} \quad (6)$$

This was the relative formula of the strength of the penetrated X-ray and the substance density. Similarly, the relative formula of the strength of the penetrated X-ray and the substance density when X-ray passed through a mixture was

$$I=(1+n)I_0e^{-\rho(w_1\mu_{m1}+w_2\mu_{m2}+w_3\mu_{m3}+\Lambda)T}$$

$$I=(1+n)I_0e^{-\rho(w_1k_1\lambda_1^3z_1^3+w_2k_2\lambda_2^3z_2^3+w_3k_3\lambda_3^3z_3^3+\Lambda)T}$$

To same CT image, the equivalent wavelength and the factor was similar, so

$$I\approx(1+n)I_0e^{-\rho k\lambda^3(w_1z_1^3+w_2z_2^3+w_3z_3^3+\Lambda)T} \quad (7)$$

Because there was

$$\rho=Q/V=Q/(HS), \text{ and}$$

$$W_i=Q_i/Q$$

formula (7) could be write as

$$I=(1+n)I_0e^{-Qk\lambda^3(Q_1/Qz_1^3+Q_2/Qz_2^3+Q_3/Qz_3^3+\Lambda)T/(HS)}$$

$$I=(1+n)I_0e^{-k\lambda^3(Q_1z_1^3+Q_2z_2^3+Q_3z_3^3+\Lambda)T/(HS)} \quad (8)$$

In this formula Q … the total weight of the object;

Q_i …the percent weight of each elements, i=1, 2, 3, …;

H … the scan thickness of CT image;

S … the substances area in CT image

It was directly to be seen from formula (6) and (7) that the strength of the penetrated X-ray was not in linear proportion to the substance density, but was an exponent of it. That was hard to distinguish the different density substances on CT image that was showed in grey scale. The true CT image that we saw was after processing with linearization and reducing voice and a serious math revising. The values of CT on the image had been in proportion to its substance density approximately, but not exactly in proportion to the density. Besides the substance density, the values of CT were affected with many factors, such as the incidence X-ray strength and the scanning thickness and the factors of the detectors and the distance of the X-ray passed throughout the object, and the area of the substance of the scan section etc. The incidence X-ray strength was in proportion to the square of voltage times the electric current of the testing. The relation between CT values and each factor of testing were discussed follow.

3.1 The relative of CT values with the voltage

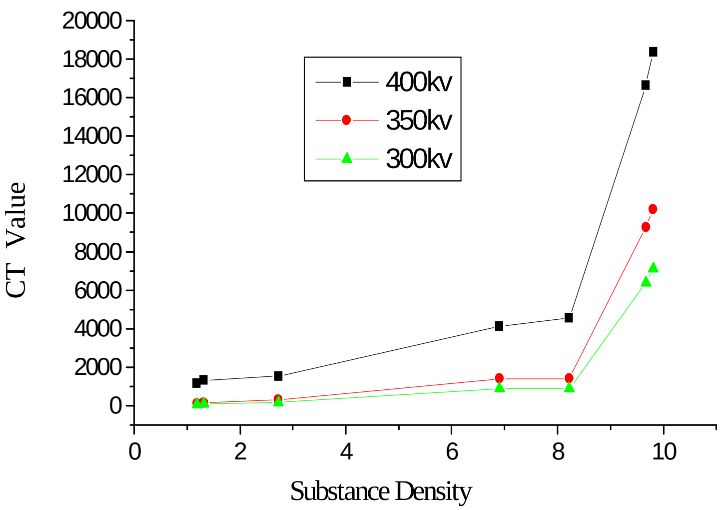

Fig.1 the curve between CT values and the substances density on different testing voltage

While the testing of ICT, to equal-power machine, the factors that could be chosen were the testing field, the testing voltage, the scanning thickness, the factors of the detectors, and the position of scanning etc. To non-equal power machine, the testing electric current was chosen yet. Fig.1 was the curve between CT values and the substances density on different testing voltage and the same other testing factors.

Seen from fig.1, when the testing voltage was different, the curve slope was not the same. The higher the testing voltage, the wider the distributing bound of CT value, the larger the curve slope. In other words, changed testing voltage, the dynamic range of image was variety only, namely the resolution ratio of the density was changed, but not changed the distribution character of the image. So, in order to make certain the substance density, it was need to use larger slope curve as admitted, namely to increase the dynamic range of image with to the best of increasing the testing voltage.

3.2 The relative of CT values with the scanning thickness

Fig.2 was the curve between CT values and the substances density on different scanning thickness and the same other testing factors.

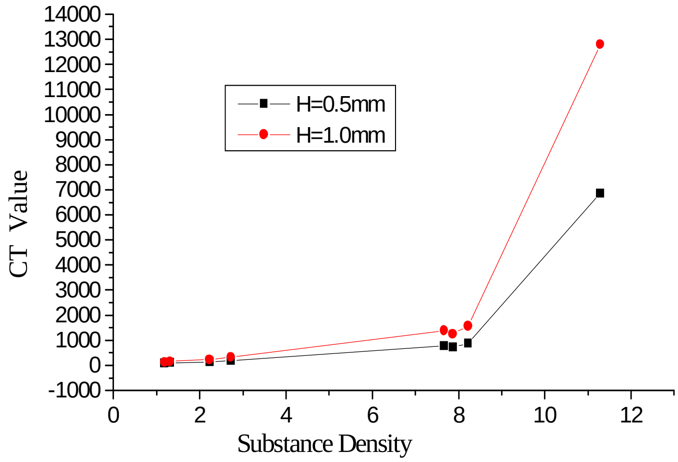

Fig.2 the curve between CT values and the substances density on different scanning thickness

Seen from fig.2, when the scanning thickness was different, the curve slope was not the same. The higher the scanning thickness, the wider the distributing bound of CT value, the larger the curve slope. In other words, changed scanning thickness, the dynamic range of image was variety only, namely the resolution ratio of the density was changed, but not the changed distribution character of the image. So, in order to make certain the substance density, it was need to use larger slope curve as admitted, namely to increase the dynamic range of image with to the best of increasing the scanning thickness for getting larger slope curve.

3.3 The relative of CT values with the factors of the detectors

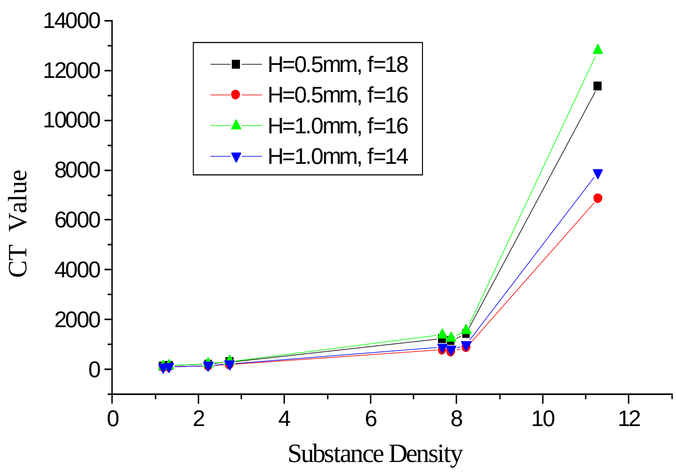

Fig.3 the curve between CT values and the substances density on different detector factors

Fig.3 was the curve between CT values and the substances density on different detector factors and the same other testing factors.

Seen from fig.3, when the detector factors were different, the curve slope was not the same. The higher the detector factor, the wider the distributing bound of CT value, the larger the curve slope. In other words, changed detector factors, the dynamic range of image was variety only, namely the resolution ratio of the density was changed, but not changed the distribution character of the image. So, in order to make certain the substance density, it was need to use larger slope curve as admitted, namely to increase the dynamic range of image with to the best of increasing the detector factors.

3.4 The relation between CT values with the density

It was educed from the results of 3.1~3.3 sections that choosing different testing factors changed only the dynamic range of the testing data, but not the curve character of the relation between CT values and substances density when the substances of structure was fixed on.

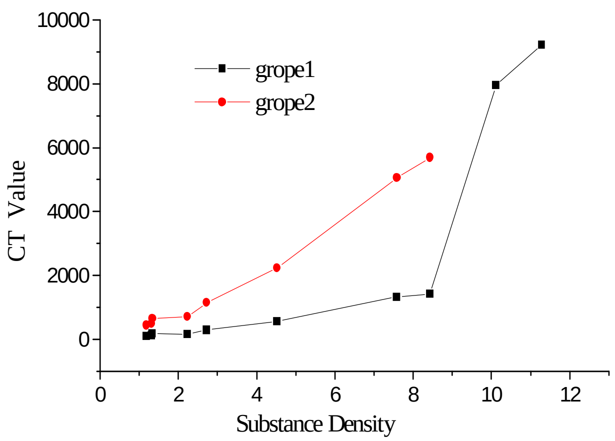

Fig.4 the curve between CT values and the substances density on different substances

Fig.4 showed the curve between CT values and substances density when two gropes specimen testing factors were the same. The second grope specimen was taken out lead and tin two substances compared with the first grope, and the other substances were the same. In primary researching for the relation between CT values and the substances density, ether alloys or mixtures were chosen here as specimen. The second grope specimen in fig.4 was made up of alloys mostly and that had closely cross section areas. Its relation curve between CT values and density was in line approximately. The positions of the sampling points departure from the fitting line accorded with the result of formula (6) ~ (8). The questions about affecting of the distance of the X-ray passed throughout the object and the area of the substances of the scan section etc. were not discussed here yet. These questions would discuss in quantization determining the relation between CT values and substance density.

4. Conclusion

The technique of nondestructive testing of ICT possessed in wide use. It was used in testing to not only single part, but also to the structure that had many materials within it. Combined with modern technology could improve highly the speed in the new product's fetched in and renovated and ameliorated, at the same time to increase the reliability of the new product research. The research about the relation between CT values and density ought to do further and to do from qualitative analysis to quantitative analysis using the quantitative testing of ICT.

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