Radiation contrast improvement by suitable choice of x-ray radiation spectrum

Mazin F. Mahrok , Thamir A. Jabbar , Adnan A. Abdulfattah

Department of Physics, College of Science, Al-Nahrain University, Iraq

Abstract

Different bremsstrahlung spectra from tungsten anode x-ray tube generated at 30, 40 and 50 kV have been examined theoretically and experimentally for an attempt to find a most suitable spectrum to radiograph a test object of 0.01 cm thickness of Cu and Ag. The high contrast using this suitable spectrum is demonstrated and the possible effects of fluorescent radiation are discussed.

Keywords
Radiation contrast
x-ray radiation.

Article info
Received: Mar. 2010
Accepted: Apr. 2010
Published: Jan. 2011

تحسين التباين الاشعاعي بالاختيار المناسب لطيف الاشعة السينية

مازن فضيل محروك، ثامر عبد الجبار، عدنان عبد اللطيف عبد الفتاح

قسم الفيزياء، كلية العلوم، جامعة النهرين/ بغداد-العراق

الخلاصه

تم اختيار اطياف اشعة كبح مختلفة منبعثة من انبوب الاشعة السينية باستخدام هدف التنكستن بفرق جهد 30 ،40 و 50 كيلو فولت نظريا وعمليا في محاولة لايجاد طيف مناسب لتصوير الجسم الاختباري المتكون من النحاس والفضة بسمك 0.01 سم شعاعيا.جرى تحقيق التباين الاشعاعي العالي باستخدام هذا الطيف المناسب وكذلك توضيح تاثيرات الاشعة التفلورية.

Introduction

The discovery of x-ray by Roentgen in 1895 attracted public attention more than any other discovery made by man. The fact that x-rays permitted one to "see" through opaque objects was sensational. Radiography may be considered as the projection of internal structure of an object onto an external recording medium.

Radiography is traditionally performed using the broad spectrum of x – ray that generated by hitting target materials with energetic electrons. However, when radiography an object in which two adjacent regions contain two different elements, it is clear that maximum contrast between these regions will be achieved by using bremsstrahlung spectrum whose energies are contained between the K – absorption edges (Kab)'s of these two elements, fig.(1) [1].

In fact the contrast is reversed out side these absorption edges.

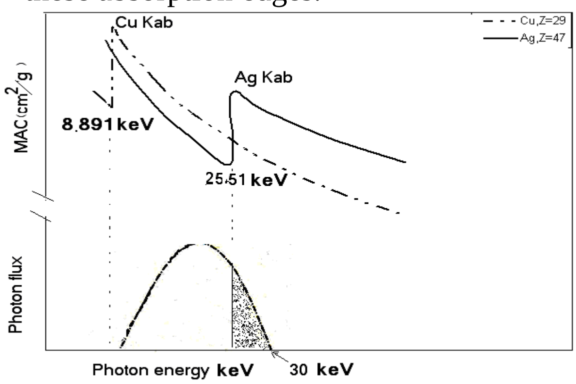

Fig 1. Mass absorption coefficient curves for Cu and Ag together with 30 kV x-ray energy spectrum as a functions of energy.[1]

However, if (Kab) of Ag (as shown in fig.1) is situated somewhere between low and high energy side of the bremsstrahlung spectrum, then the net contrast may be very small. The need to obtain high contrast in radiography, made Clark and Shafer[2] to use monoenergetic x- rays and molybdenum polychromatic radiation for radiography They found that the latter gave greater contrast than copper radiation.

The possibility of employing Ag K x-rays to radiograph foils of Mo-Cd placed side by side has been discussed by Mahrok et al .[3]. They obtained high contrast by the proper selection of x-ray energies and foils. In order to enhance the contrast of some areas in the body and making them appear whiter, Erkonen and Smith [4] suggested the use of contrast media. Dilmanian et al [5] used gadolinium (Gd, Z=64) instead of iodine as a safe contrast agents for radiography in an attempt to enhance image quality. But all beam tailoring method they used involve multi-fold loss of x – ray intensity. Their results indicate that the method could be implemented in clinical CT if x-ray tubes with about twice higher output become available. However, it was realized later by Thomson [6] and others that a comprehensive literature review revealed that according to experimental data Gd-based contrast media have more nephrotoxic potential than iodine; therefore Gd should not replace iodine in patients with renal insufficiency for radiographic examination. In this paper, an attempt is made to obtain high contrast for Cu–Ag foils placed side by side using suitable broad spectrum radiation and to prove that if the radiation spectrum is not properly selected then the net contrast may be very low.

Theoretical Calculations

Radiation contrast, as defined by Meredith and Massey [7] is the logarithm of the ratio of the x-ray intensity transmitted through one part of the radiography object to that through another part. In order to examine the effect of selecting broad bremsstrahlung spectrum on contrast, a test object of 0.01 cm thickness of Cu and Ag each of them is a square of 2cm x 2cm placed side by side is considered. The mass absorption coefficient MAC of Cu and Ag together with the incident spectrum as functions of energy is shown in fig.(1). It is clear that the incident spectrum is selected such that the majority of the photons in it is contained between the (Kab)'s of Cu and Ag where the difference in MAC is maximum. Hence high contrast is expected. The Kab for Cu and Ag are at 8.981 keV and 25.514 keV, respectively. The contrast calculation for the broad bremsstrahlung spectrum depends on knowledge of photon spectrum and relevant absorption coefficient of the radio graphed object.

The effect of polyenergetic beam of x-ray on the contrast can be obtained only by calculation the transmitted intensities for any energy contained in the incident beam and integrating these intensities over the whole range of energies, [8]. However, when considering incident radiation of energy above Kab of an element to be radiographed, it is necessary to estimate the effect of the re-radiated florescent radiation as this was found to contribute significantly to the total transmitted intensity. Accordingly, Cu is expected to emit fluorescent radiation because the incident energy spectrum (10 - 30) keV is higher than the (Kab) energy (8.891) keV of Cu .However, only the shaded part of the incident spectrum is higher than the (Kab) of Ag and capable to produce K fluorescence radiation. Therefore, the mathematical expression for radiation contrast (C_R) for Cu – Ag test object will be, [7].

$$C_R = \text{Log} \frac{\sum_i (T)_{Ag} + \sum_i (TF)_{Ag}}{\sum_i (T)_{Cu} + \sum_i (TF)_{Cu}} \qquad (1)$$

where $i = 1, 2, 3, \ldots$ etc.
The transmission intensities are defined mathematically as

$$\sum_i (T)_{Ag} = \sum_i B_i \exp[-(\mu_i)_{Ag}\ (\rho)_{Ag}\ t] \quad (2)$$

$$\sum_i (T)_{Cu} = \sum_i B_i \exp[-(\mu_i)_{Cu}\ (\rho)_{Cu}\ t] \quad (3)$$

where B_i is the incident bremsstrahlung intensity for the energy E_i . The symbols $(\mu_i)_{Cu}$ and $(\mu_i)_{Ag}$ are the MAC in cm^2 /g corresponding to the energy E_i of the incident spectrum for copper and silver respectively.
$(\rho)_{Ag} = 10.5$ g/cm^3, $(\rho)_{Cu} = 8.96$ g/cm^3 and t = 0.01 cm. Where $(\rho)_{Ag}$ and $(\rho)_{Cu}$ are the densities of Ag and Cu in g/cm^3 respectively, (t) is the thickness in cm for each Ag and Cu.

Values of MAC in cm^2/g for all the photon energies E_i used in this paper were obtained partly directly and partly by interpolating the data given by Storm and Israel [1] . $\Sigma\,(TF)_{Cu}$ is the summation of the K-shell fluorescent radiation emitted from Cu foil in the direction of the x-ray film. This was obtained from knowledge of fluorescence yield W_k given by Bambyneck et al.[9].

In order to calculate the contribution of K-shell fluorescent radiation that emitted from Cu foil towards the x-ray film, the thickness of Cu foil was considered to be divided into 100 section of equal thickness. The fraction of the incident radiation absorbed in each slab was calculated by applying the exponential law. Then the fraction of the fluorescent radiation transmitted through the remainder of Cu foil was calculated by applying the appropriate absorption coefficient. The incident radiation of intensity (B_i) is attenuated by X_i (see fig.2), thus the intensity arrived at ΔX will be,

$$B_i \exp(-(\mu_i)_{Cu}(\rho)_{Cu}\ X_i)$$

The intensity absorbed in the slab (ΔX) will be :

$$B_i \exp(-(\mu_i)_{Cu}\ (\rho)_{Cu}\ X_i) - B_i \exp(-(\mu_i)_{Cu}(\rho)_{Cu}\ X_i)\ \exp(-(\mu_i)_{Cu}\ (\rho)_{Cu}\ \Delta X)$$

$$= B_i \exp(-(\mu_i)_{Cu}(\rho)_{Cu}\ X_i)\ [1 - \exp(-(\mu_i)_{Cu}(\rho)_{Cu}\ \Delta X)]$$

The above expression has to be multiplied by the fluorescence yield of Cu, that is $(W_k)_{Cu}$, to obtain the total fluorescence emitted from the slab (ΔX); and then divided by 2.2 to allow for the geometry of Cu foil to become that part of the total fluorescence emitted from Cu in the direction of the x-ray film . This is written as follows,

$$B_i \exp(-(\mu_i)_{Cu}(\rho)_{Cu}\ X_i)\ [1 - \exp(-(\mu_i)_{Cu}\ (\rho)_{Cu}\ \Delta X)]\ (W_k)_{Cu}/2.2$$

Now this expression is attenuated by the rest of Cu foil, that is Yi, before leaving the foil and arriving at the x-ray film .
Hence,

$$\sum_i (TF)_{Cu} = \sum_i B_i \exp(-(\mu_i)_{Cu}(\rho)_{Cu}\ X_i)\ [1 - \exp(-(\mu_i)_{Cu}\ (\rho)_{Cu}\ \Delta X)]$$

$$[(W_k)_{Cu}/2.2]\ \exp(-(\mu)_{Cu}(\rho)_{Cu}\ Y_i))$$

Rearrange,,

$$\sum_i (TF)_{Cu} = \sum_i B_i \exp[-((\mu_i)_{Cu}(\rho)_{Cu}\ X_i + (\mu)_{Cu}\ (\rho)_{Cu}\ Y_i)]$$

$$[1 - \exp(-(\mu_i)_{Cu}(\rho)_{Cu}\ \Delta X)]\ [(W_k)_{Cu}/2.2] \quad (4)$$

The summation in equation(4) is done for all the photon intensities contained in the incident x-ray spectrum , and was repeated for each slab.$(\mu)_{Cu}$ refers to the MAC for Cu with respect to Cu K x-ray energy and equals to 51.27 cm^2/g [1]and $(W_k)_{Cu} = 0.439$[9].
The significance of other symbols in the above equation is shown in fig. (2).

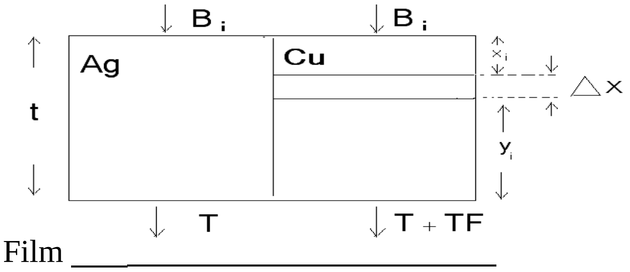

Fig. 2.Transmitted and fluorescence radiation from Cu-Ag test object

Similarly, for Ag, the total fluorescence arrived at the x-ray film will be

$$\sum_i (TF)_{Ag} = \sum_i B_i \exp[-((\mu_i)_{Ag} (\rho)_{Ag} X_i + (\mu)_{Ag} (\rho)_{Ag} Y_i)]$$

$$[1 - \exp(-(\mu_i)_{Ag} (\rho)_{Ag} \Delta X)]\,[(W_k)_{Ag} / 2.2] \quad (5)$$

where $(\mu)_{Ag}$ is the MAC for Ag with respect to Ag K x-ray energy and equal to 14.88 cm^2/g[1],and $(W_k)_{Ag}$ =0.831[9]
Equation 1 is applied for each one of the bremsstrahlung spectrum generated at 30 , 40 and 50 kV individually . The values of C_R for Cu-Ag test object expected from these spectra are tabulated in table 1.

Experiments and Results

The Cu-Ag test object described above has been radio graphed using bremsstrahlung spectrum from an x-ray tube operated at 30, 40 and 50 kV. The radiographs are shown in fig.(3).

Fig.3.Radiograph of Cu-Ag test object taken with x-ray tube operated at 30 kV.

The ultimate contrast UC on the x-ray film was measured by optical densitometer. The optical density OD of the x-ray film at a point is a measure of the degree of blackness in that point. OD is expressed by

$$OD = \log (Io/It) \quad (6)$$

Where Io is the intensity of visible light incident on small area of the film, and It is the intensity of the light transmitted by same area of the film. The ultimate contrast UC measured on the x-ray film is shown in table.1 .UC is the difference in OD between two points on the x-ray film.

Table (1). Calculated and measured contrasts for Cu-Ag test object for the spectra generated at the stated voltages.

Spectrum generated at stated voltage (kV)	Calculated radiation contrast (C_R)	Measured ultimate contrast (UC)
30	0.39	1.5
40	-0.106	-0.4
50	-0.343	-1.07

The values of UC are always higher than those of C_R for the same system .Because of the calculated C_R value represent the contrast present in the x-ray pattern just after emerging from the radio graphed object. The image formed here is called latent image. While the UC value is the contrast measured in the x-ray film and this normally higher than C_R because the x-ray film acts as an amplifier, where each X-ray intensities in the pattern emerging from the object is multiplied by the slope of the characteristic curve of the x-ray film to end up with UC.
Here

$$UC = \gamma \; C_R \quad (7)$$

where γ is the slope of the straight line portion of the characteristic curve of the x-ray film.
However, in our first trail, the x-ray films were overexposed and this is the reason why γ is not really constant

Discussion and Conclusions

A close inspection of equation (1) and fig.(1), one concludes that C_R of the radio graphed object would have been better without the K-shell fluorescent radiation. Therefore, the fluorescent radiation has always negative effect on contrast.
Fluorescent radiation emitted from higher shells (L shell, etc) of Cu foil are ignored in the calculation since their energies are so small (about 1/10 the energy of Kshell

fluorescent radiation) and are highly absorbed by the x-ray film cover and hence does not have a chance of reaching the x-ray film.

In contrast calculation, the fluorescent radiation emitted from Cu is considered to be emitted as $K_{\alpha 1}$ as this line is the most intense line in K series of Cu.The same consideration was applied for Ag.

The detailed spectral information for theoretical calculation of contrast were taken from Fewell and Shuping[10] and Birch et al.[11] .These spectra are similar to the practical spectra used to radiograph the test object as they all are obtained from x-ray tube with tungsten target at 30,40 and 50 kV.

The shaded part of the x-ray spectrum generated at 30 kV in fig.(1). is small compared to those generated at 40 and 50 kV.Larger number of photons in the shaded area means more fluorescence radiation from Ag foil because these photons are higher in energy than the Kab of Ag. However, this fluorescent radiation has negative effect on contrast for the thickness 0.01 cm of the test object used as it is obvious in table (1).

Calculated values of C_R as shown in table (1) demonstrate that there is marked improvement in contrast when radiograph Cu-Ag test object with x-ray spectrum (30 kV in this case) chosen to have the majority of its energy between the absorption edges of the two elements involved. The negative sign of the contrast means that the contrast is reversed for 40 and 50 kV comparable with 30kV .Here Ag is relatively more absorbing than Cu.

In table (1) UC values agree reasonably with C_R values only from the arrangement point of view because of the overexposure makes the inclusion of γ with C_R incorrect**.**

It is believed that proper selection of x-ray spectrum yields improved contrast. As well, as it is also investigated possible practical application of this technique.

References

[1] E. Storm and H. Israel: "Nucl.Data Table A7", (1970), 565.

[2] G. Clark and W.Shafer, "The technique of micro radiography and its application to metals": Transactions of American Society for Metals, 29 (1941), 732-754.

[3] M. Mahrok, D. Crumpton and P.Francois, "The application of proton induced x-ray emission to Radiography": Nuclear Instruments and Methods, 181 (1981) 105-107.

[4] E. E. William and S. L.Wilbur, "Radiology 101: The basic and fundamentals of imaging", Lippincott Williams and Wilkins, 3rd (2009).

[5] F. Dilmanian, H. Weinmann, Z. Zhong, T. Bacarian, L. Rigon, T. Button, B. Ren, X.Y. Wu, N. Zhong and H. Atkins," Tailoring x-ray beam energy spectrum to enhanced Image quality of new radiography contrast agents based on Gd or other lanthanides": Physics of Medical Imaging, 4320 (2001), 417-429.

[6] H.Thomson," Gadolinium contrast media may be nephrotoxic even at approved doses": European Radiology, 14(9), Sept.(2004).

[7] W. Meredith, and B. Massey, "Fundemental Physics of Radiology" John Wright, Bristol (1977) 235.

[8] W. Betteridge, ," A further handbook of industrial radiology", ed. W. J. Wilthire, Edward, London (1957), 226.

[9] W.Bambynek, B.Crasemann, R. Fink, H.Freund, H. Mark., C.D.Swift, R.Price and P.Rao: Rev. Mod. Phys., 44(1972), 716.

[10] T. Fewell and M. Shuping, "A comparison of mammographic x-ray spectra": Radiology, 128 (1978), 211-216

[11] R Birch., M.Marshall and G.Ardran, "Cataloqe of spectral data for diagnostic x-rays, Hospital physicists association, Scientific Report Series 30 (1979).