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Integrated Methods of Correction of Attenuation in Compton Tomographies

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Abstract

One of the basic preventing factors in reconstruction of the image of internal structure of objects in compton tomography is easing primary and absent-minded beams in the previous layers. Works of many authors [1-6] are devoted to the analysis of correction of influence of absorption. However practical utility of these researches is limited to isolation of considered physical models from a reality. The basic lack of known works is neglected differently thickness a controllable product on section and use of past radiation for correction of attenuation in the previous layers. In clause results of the analysis of opportunities of an iterative method of correction of attenuation are resulted, and also the method of physical correction of attenuation of a primary beam is described due to application of two sources with different energy.

In Compton tomography the information on density of a material in the given element of volume are carried with a stream of unitary absent-minded quantums which left this volume and have got in the detector. In clause the methods of integrated correction developed in scientific research institute IN TPU the attenuations based on iterative procedure of correction of the measured data and on the basis of use of two sources of radiation with different energy are described.

1. A METHOD OF LEVEL-BY-LEVEL CORRECTION

Element of volume of controllable object within the limits of which the density practically does not change, name "elob". I.e. the considered situation meets to a case when sizes DV do not exceed the sizes "elob" [1-6].

Let's consider the circuit of scanning of Fig. 1. A narrow beam scale of radiation from dot source S with effective energy E (poses. 1) it is formed collimator (poses. 2) also falls on controllable object.

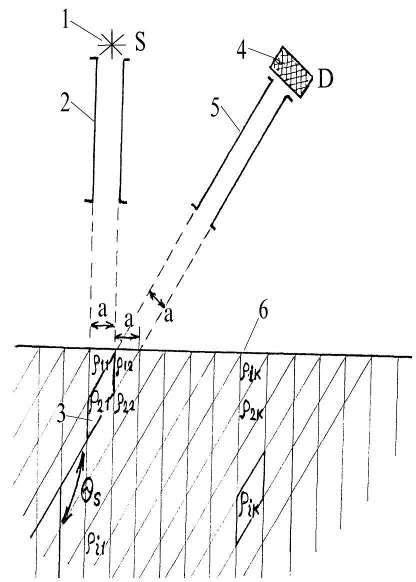


Fig. 1. The geometry of point wise scanning

Absent-minded in an element of volume of a material (poses 3) on corner θ_s radiation, passing through collimator (poses. 5), gets on the detector (poses. 4). Collimators represent channels with the area of cross-section section Ss and Sd accordingly and lengths of channels hs and hd.

Carrying out step-by-step two-coordinate scanning with step across (i.e. along controllable section), equal to the collimator's aperture a source and on a vertical, with step equal to the collimator's aperture the detector divided on $\sin\theta_s$, we conditionally break controllable section into elements of volume ("elobs") with average on "elob" in density ρ_{ik}; where i - number of a step of scanning on verticals or number of a line of matrix ρ_{ik}; k - number of a step of scanning across or number of a column in matrix ρ_{ik}. Dispersion of quantums in these "elobs" causes occurrence of signals on the detector.

As shown in [1], the maximum of a signal in the detector, received at input DV in a product, unequivocally defines density of the top layer. Scanning across the first near-surface a line "elobs" for what point wise move system the source - detector to in parallel controllable section, is received on the detector with the signals unequivocally connected with ρ_{ik} of these elobs.

For simplicity of a reasoning we shall count collimator's apertures identical and equal "á".

The reflectance-exit from a line in length "y" is equal

$$N_{1k}(y)=\int_0^y dN_{1k}(y)=\frac{N_0}{a}\frac{d\sigma_\rho}{d\Omega}\cdot(1-\exp(-\rho_{1k}a(\mu_\rho^0+ +\sqrt{2}\mu_\rho^s)))\cdot\frac{\Gamma}{\mu_\rho^0+\sqrt{2}\mu_\rho^s}\cdot\frac{z}{M}N_A \quad (1)$$

Full reflectance-exit from the disseminating volume with coordinates (1, к)

$$N_{1k}(y)=\int_0^a (N_{1k}(y)dy=\frac{N_0}{a}\frac{d\sigma_\rho}{d\Omega}\cdot\frac{\Gamma}{\rho_{1k}\left(\mu_\rho^0+\sqrt{2}\mu_\rho^s\right)^2}\cdot(1-\exp(-\rho_{1k}a(\mu_\rho^0+\sqrt{2}\mu_\rho^s)))\cdot\frac{z}{M}N_A \quad (2)$$

Where N_{lk} - quantity of quantums, absent-minded in "elob" ρ_{ik} and registered by the detector in unit of time;

μ^0_ρ, μ^S_ρ - mass factors of easing of radiation with energies E_0, E_s, where E_s - energy of an absent-minded beam is equal

$$E_s = \frac{E_0}{1+\alpha(1-\cos\theta_s)} \qquad (3)$$

If energy of radiation lays in limits 0,15-1,5MeV with good accuracy it is possible to put

$$\mu_\rho = \sigma_\rho \qquad (4)$$

The decision of the transcendental equation (2) be relative ρ_{1k} is carried out by a numerical method. In result we receive a file of values ρ_{1k}.

Let's move system the source - detector on a step on a vertical and it is again feasible horizontal scanning. The signal registered by the detector at scanning of the second lines "elobs", is connected to easing in "elobs" the first lines.

$$N_{2k} = \frac{N_0}{a}\frac{d\sigma_\rho}{d\Omega}\Gamma(1-\exp(-a(\mu_\rho\rho_{1k}+\mu^s_\rho\sqrt{2}\rho_{1k+1})) \qquad (5)$$
$$\frac{\rho_{1k}}{\mu^0_\rho\rho_{1k}+\mu^s_\rho\sqrt{2}\rho_{1k+1}}\frac{1-\exp(-a(\mu^0_\rho\rho_{1k}+\mu^s_\rho\sqrt{2}\rho_{1k}))}{\mu^0_\rho\rho_{1k}+\mu^s_\rho\sqrt{2}\rho_{1k}}\frac{z}{M}N_A$$

After the substitution, (2) densityρ_{1k} calculated with the help in (5) it is received the transcendental equation be relativeρ_{2k}, which is solved similarly (2). Also density of all underlying layers is restored. The signal corresponding to dispersion in an element with indexes i, k, looks like.

$$N_{ik} = \frac{N_0}{a}\frac{d\sigma_\rho}{d\Omega}\Gamma(1-\exp(-a(\mu^0_\rho\rho_{i-1,k}+\mu^s_\rho\sqrt{2}\rho_{1k+i-1})))\cdot$$
$$\cdot\frac{\rho_{ik}}{\mu^0_\rho\rho_{i-1,k}+\mu^s_\rho\sqrt{2}\rho_{1k+i-1}}\cdot\frac{1-\exp(-a(\mu^0_\rho\rho_{i-1,k}+\mu^s_\rho\sqrt{2}\rho_{i-1,k}))}{\mu^0_\rho\rho_{i-1,k}+\mu^s_\rho\sqrt{2}\rho_{i-1,k}}\cdot$$
$$\cdot\exp(-a(\mu^0_\rho\sum_{j=2}^{j=i-1}\rho_{j,k}+\sqrt{2}\mu^s_\rho\sum_{j=2}^{j=i-1}\rho_{j,k}))\frac{z}{M}N_A \qquad (6)$$

Solving the equation (6) on each step of scanning on depth, we receive distribution of density in cross-section section with the spatial sanction determined in the sizes of beams. Such recurrent algorithm automatically corrects easing primary and absent-minded radiations. The certain difficulties are represented with the account of divergence of beams and repeated dispersion. At practical realization of algorithm divergence is taken into account "on the average". For this purpose in expression (5) in geometrical factor Γ the amendment g, equal to the relation of the area of section real DV to Γ0, calculated for not missing beams is entered at the same sizes collimators.

Lack of the marked algorithm is also influence of roughness of a surface since at poor quality of starting iterations the error of calculation ρ_{ik} with increase in depth collects. For reduction of this error by surfaces of object it is offered [2] to place a plate from a homogeneous material with relatives nuclear number and in density and with the thickness a few exceeding size DV on depth. The starting position before scanning - DV is entirely in a reference plate.

The given algorithm point wise scanning provides the spatial sanction of 2,4 mm on depth and 1mm in a longitudinal direction, therefore it use in a mode " FAST VIEWING " for detection of large local or extended defects and various bookmarks.

2. A method of two energies

Opportunity of definition of value of density at entrance DV in the object allows to define distribution of density on depth, using the iterative algorithm described above [8]. In this algorithm the error of measurement ρ collects оп to a measure of increase in depth of a layer. It is possible to provide a smaller error if to carry out physical correction of easing. The idea of realization of such correction is submitted in [9-13] and based on measurement of streams back absent-minded radiation in various positions of a source and the detector and at different energies of primary radiation. The basic lack of known ways – is necessity of bilateral access to object of the control. We [14] develop a method of physical correction of easing of a primary beam, free from the marked lack.

Let's consider Fig. 2. In positions 1 radiation with energy E_1 goes to a product. In detector D_1 the stream of radiation dN_1, absent-minded in elob on depth X (a layer dx) gets. For this case, with the account (3.1) the ratio is fair

$$dN_1 = J_1 C_1 K_1 \cdot e^{-\left(\mu_1 + \mu_{s1}/\cos\theta\right)x} dx \qquad (7)$$

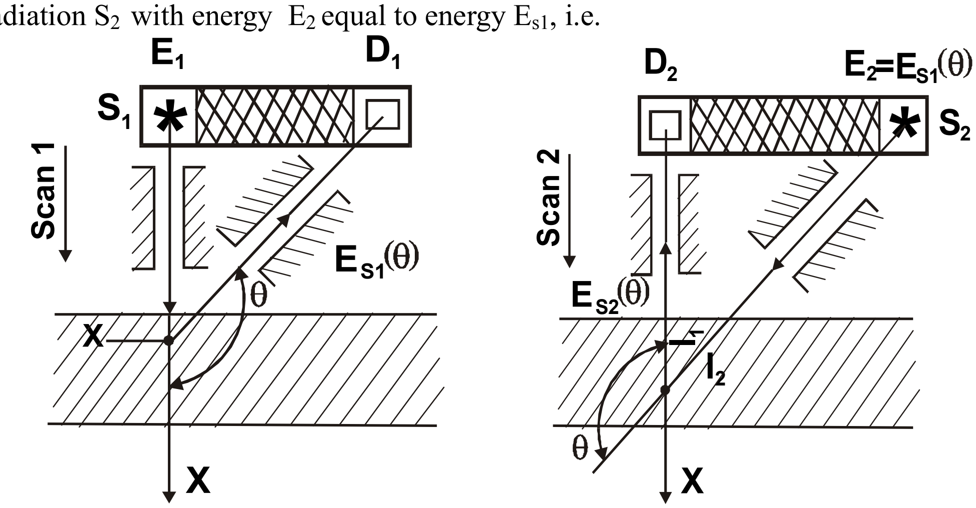
where μ_1 and μ_{s1} - linear factors of easing of radiation of a source with energy E_1 and radiations with energy E_{s1}, absent-minded on corner θ

$$K_1 = \left(\frac{d\sigma}{d\Omega}\right)_1 N \frac{Z}{A} \rho(x) \qquad (8)$$

where $\rho(x)$ - density of a body on depth X;

N, Z, A - accordingly number Avogadro, nuclear number and mass number of a material.

Let's change now a position on 2. On a place of detector D_1 we shall place a source of radiation S_2 with energy E_2 equal to energy E_{s1}, i.e.



a) a position 1 б) a position 2

Fig. 2. A method of two energies. Explanations are in the text.

$$E_2 = \frac{E_1}{1 + \frac{E_1}{m_0 C^2}(1 - \cos\theta)} \quad (9)$$

On a place of source E_1 we shall place detector D_2. The stream of quantums from a layer dx on depth X is equal

$$dN_2 = J_2 C_2 K_2 \cdot e^{-\left(\mu_{s1} + \mu_{s2}/\cos\theta\right)x} dx \quad (10)$$

where $K_2 = \left(\frac{d\sigma}{d\Omega}\right)_2 N \frac{Z}{A} \rho(x)$; (11)

μ_{s2} - factor of linear easing for quantums from source S_2, with energy E_2, absent-minded on corner θ.

For non-uniform object on section in parameters an exhibitor in expressions (7, 10) it is necessary instead of factors of easing μ_1, μ_{s1}, μ_{s2} to substitute linear integrals corresponding to them.

$$\mu = \int_l \mu(x) dx \quad (12)$$

Hence a source of an error of measurement of density in a layer dx on depth x is change of linear factor of easing of a primary beam of movement of quantums from source S_1 up to the disseminating volume on depth x and from DV up to the detector on a way $x/\cos\theta$.

Let's calculate the relation of streams of quantums in detectors 1 and 2 in positions 1 and 2.

$$\frac{dN_1}{dN_2} = \frac{J_1 C_1 K_1}{J_2 C_2 K_2} \cdot e^{-\left(\mu_1 - \mu_{s2}\right)x} \quad (13)$$

In this expression easing on a site l_2 with factor μ_{s1} is absent, i.e. is excluded "physically". The relation

$$\frac{J_1 C_1 K_1}{J_2 C_2 K_2} = a = const \quad (14)$$

For set corner θ.

Correction of change of linear factor of easing μ_1 and μ_{s2} on a way l_1 can be carried out by direct measurement of density of the first layer (a case when previous layers are not present) on amplitude of the reflected signal in a maximum and use of recurrent algorithm of calculation of density of the subsequent layers.

Take the logarithm (13). We shall receive

$$x\left(\mu_1 - \mu_{s2}\right) = \ln\left(a \frac{N_2}{N_1}\right) \quad (15)$$

Signs on differentials here are omitted. We shall pass to the final sums for linear factors of easing μ_1 and μ_{s2} and we shall express them through files and.

Then for a layer ΔX on depth x_i, having expression for the logarithm of the relation of streams in detectors D_1 and D_2 is possible to write down density ρ_i

$$X_i\left(\sum_{i=1}^{n} \mu_1^m \rho_i - \sum_{i=1}^{n} \mu_{s2}^m \rho_i\right) = \ln\left(a \frac{N_{2i}}{N_{1i}}\right) \quad (16)$$

where n - amount of the layers previous i to a layer.

Taking out from a bracket density i-th layerρ_i, we shall write down

$$X_i\rho_i\left(\sum_{i=1}^{n}\mu_1^m-\sum_{i=1}^{n}\mu_{s2}^m\rho_i\right)=\ln\left(a\frac{N_{2i}}{N_{1i}}\right) \quad (17)$$

For the first layer (i=1) it is possible to calculate density, it will be equal

$$\rho_1=\frac{1}{X_1\left(\mu_1-\mu_{s2}\right)}\ln\left(a\frac{N_{2i}}{N_{1i}}\right) \quad (18)$$

Scanning object rigidly - connected system a source - the detector on x, we shall receive on the second step of moving

$$X_2\left(\mu_1^m\rho_1+\mu_1^m\rho_2-\mu_{s2}^m\rho_1-\mu_{s2}^m\rho_2\right)=\ln\left(a\frac{N_{21}}{N_{12}}\right) \quad (19)$$

From this expression we receive density of layer ρ_2

$$\rho_2=\frac{1}{X_2\left(\mu_1^m-\mu_{2s}^m\right)}\ln\left(a\frac{N_{22}}{N_{11}}\right)-\rho_1 \quad (20)$$

On the third step of moving we shall receive

$$\rho_3=\frac{1}{X_3\left(\mu_1^m-\mu_{2s}^m\right)}\ln\left(a\frac{N_{23}}{N_{13}}\right)-\rho_1-\rho_2 \quad (21)$$

Having lead full process of scanning, we shall receive files of numbers N_{2i} and N_{1i}, corresponding to values of streams of quantums in detectors D_1 and D_2.
Having these files, density i a layer on depth X_i it is calculated under the recurrent formula

$$\rho_i=\frac{1}{X_i\left(\mu_1^m-\mu_{2s}^m\right)}\ln\left(a\frac{N_{2i}}{N_{1i}}\right)-\sum_{k=1}^{i-1}\rho_1 \quad (22)$$

For realization of a method of two energies the device is developed, which block diagram contains the measuring block (the central source and system of ring detectors + the central detector and system of ring sources), the mechanism of scanning, the circuit of management, the processor, the intensified display.
As sources of radiation 121 day, and a source ^{153}Cd with energy 100кэВ and a half-life period of 241,6 day are used an isotope ^{181}W, having energy E=150кэВ, a half-life period.

The measuring block is slowly brought by the mechanism of moving to object of the control. During the first moment work the central source (S_1) and system of detectors D_1 allocated on a circle. Reflected from object of the control quantums are registered by detector D_1 from which exit the information acts in the block of the peak analysis. At the moment of achievement of a maximum on the mechanism of scanning the signal «Stop on a maximum» acts. On value N_{Smax} and E_1 in the processor the density of first layer ρ_1, which in the given system is reference is calculated. On it the binding (adjustment) of sensitivity of system is carried out.

Then the measuring block falls on a step ΔX, values N_{12} and N_{22} are measured serially. On them density ρ_2 is calculated and acts in memory. And so on. In a result on the display the image of distribution of density on section is under construction.

Conclusions

The lead analysis shows an opportunity of application of mathematical procedure of step-by-step correction of attenuation in the previous layers in case of use of unilateral access to a controllable product. Thus the opportunity of reconstruction of distribution of density in cross-section section of object is shown. The opportunity is shown also and the circuit of scanning is developed. Based on use of sources of radiation with two energies, completely excluding easing of a primary beam of radiation in the previous layers.

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