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Simulation of Beam Hardening in Industrial CT with x-ray and Monoenergetic Source by Monte Carlo Code

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ABSTRACT

Determination of defects in industrial part is vary vitally, an industrial CT scan determinate defect in industrial part .one of causes that decrease accuracy in determination of defect is beam Harding error. a proper correction algorithm for decreasing of beam hardening error is necessary for various industrial.

In this study an industrial CT scan with two sources, mono energy source and X-Ray spectrum with 140kv and 225kv has simulated with MCNP4C code and MATLAB7.3 software. In this study we evaluated beam hardening error. Output profiles from x-ray spectrum corrected with a proper correction algorithm and compared with mono energy output profiles.

Keywords: industrial CT scan, beam hardening, Monte Carlo.

1- INTRODUCTION

The X-ray beam used in computed tomography (CT) consists of photons at different energies. When an x-ray beam passes through the material, its attenuation at any point depends on the material at that point and on the energy distribution (spectrum) of the beam. The attenuation at a fixed point is generally greater for photons of lower energy and the energy distribution (spectrum) of the x-ray beam changes (hardens) as it passes through the material. This effect is called Beam hardening and induces several artifacts like cupping and dark streaks between regions of high mass density [1]. Beam hardening depends on Kvp, mA, electron density and reconstruction method [2].

K.Ramakrishna , K.Muralidhar , P.Munshi at 2005 evaluated Beam hardening spectrum of an industrial CT. for error calculation of Beam hardening they used mathematical relationship that explained by Herman in 1979 [3].

In this study we use Monte Carlo simulation, in this simulation, parameters that affect Beam hardening for different materials and 2 energy 140 kv, 225 kv evaluated.

2- MATERIALS AND METHODS

In this study we used Monte Carlo code (MCNP4C) that is a general method, for simulation of CT hardware , processing data and image reconstruction we used MATLAB 7.3 software.

This study has 3 stages. The first stage is calculation of effective attenuation factors and CT numbers for various energy and objects.

The second stage of this study is simulation of a industrial CT by MCNP4C code for monoenergetic source and a x–spectrum source, in third stage output profile of industrial CT with x-spectrum is corrected by a correction algorithm.

1-2 Calculation effective attenuation factor μ(eff)

Slop of plot $Ln\, {}^{I}\!/_{I_0}$ to thickness is effective attenuation factor μ(eff). For calculation effective attenuation factor μ(eff) it is necessary to earn X- spectrum output or monoenergtic source for various thickness.

For each point in plot $Ln\, {}^{I}\!/_{I_0}$ to thickness, program ran for with phantom and without phantom states at same thickness, program ran for 5 various phantoms at 2 energy and for 2 million photon.

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2-2 CT number calculation for two energy 140 kv and 225 kv

For calculation of CT number for each energy we assumed an effective attenuation factor. Relation to attenuation factor plots in previous section we can determine attenuation factor for each thickness then we can earn CT number from relation 1.

$$CT(x,y).No = \frac{\mu(x,y)_{-}\mu_{water}}{\mu_{water}} \qquad (1)$$

3-2 simulation of an industrial CT for 2 states, an x- spectrum and monoenergetic source

In this study a x- spectrum with 2 energy 140 kv , 225 kv is simulated. For various energy we used aluminum filters with different thickness. Simulated phantoms are cylinders that have various dimension and different materials. Thickness of phantoms is propotantioal to half value layer at assumed energy.

All phantoms are at 20 cm distance from x- spectrum.

Phantom1: a cylinder phantom with 5.78 cm radius, height 4 cm from water

Phantom2: a cylinder phantom with 0.25 cm radius, height 4 cm from lead

Phantom3: a cylinder phantom with 1 cm radius, height 4 cm from aluminum

Phantom4: two centeriod cylinder phantom with different radius that great cylinder have 5.78 cm radius from water and small phantom 0.25 cm radius from lead. Two centeriod phantoms have 4 cm height.

Phantom5: two centeriod cylinder phantom with different radius that great cylinder have 5.78 cm radius from water and small phantom 1 cm radius from aluminum. Two centeriod phantoms have 4 cm height.

75 detectors in form of an arc as a real CT are simulated; geometry for x- beam and monoenergenetic source is same. Once for x- beam and once for monoenergenetic source at (140 kv, 225 kv) for all phantoms, data are got by f5 tally.

4-2 Correction Algorithm

For correction of Beam Hardening errors, we used a combination calculation method and Monte Carlo [4].

$$AP(u,v) = Ln\frac{P_0(u,v)}{P(u,v)} + Ln\left[\frac{1}{1+SPR\,(u,v)}\right] \qquad (2)$$

The first part of relation 2 extract from MATLAB 7.3 and second part of relation 2 extract from x-beam output profile in MCNP4C space. Calculation performed due to Algorithm (Fig.1)

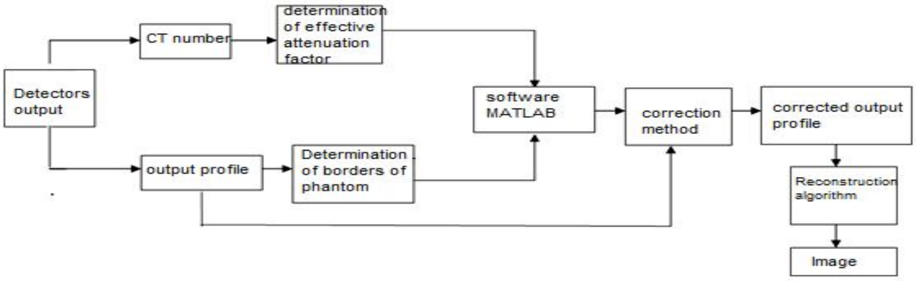


Fig.1 Correction Algorithm of Beam Hardening artifact of spectrum

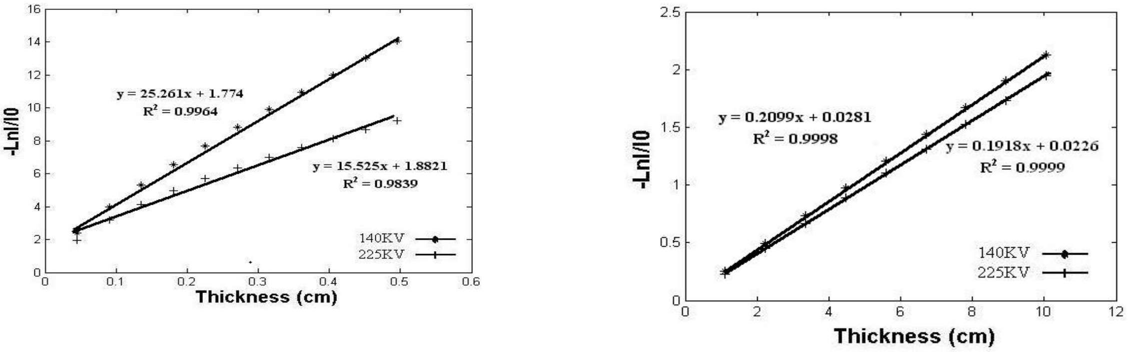
3- RESULTS

Results due to attenuation factor for 2 phantom and CT numbers of lead and aluminum are showed in Fig. 2 & 3. Radon output of X- beam profile, mono energetic source and corrected X- beam that normalized are showed in Fig.4.

For description of errors between X- spectrum, mono energetic source and corrected X-spectrum we use 3&4 relationship. Results are showed at Table 1.

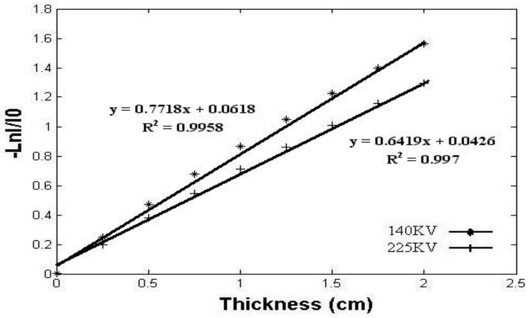
$$Error.for.Spectrum.X = \frac{Sum.Radon.for.Monoenergy - Sum.for.Spectrum.X}{Sum.Radon.for.Monoenergy} \times 100 \tag{3}$$

$$Error.for.Corrected = \frac{Sum.Radon.for.Monoenergy - Sum.for.Corrected}{Sum.Radon.for.Monoenergy} \times 100 \tag{4}$$



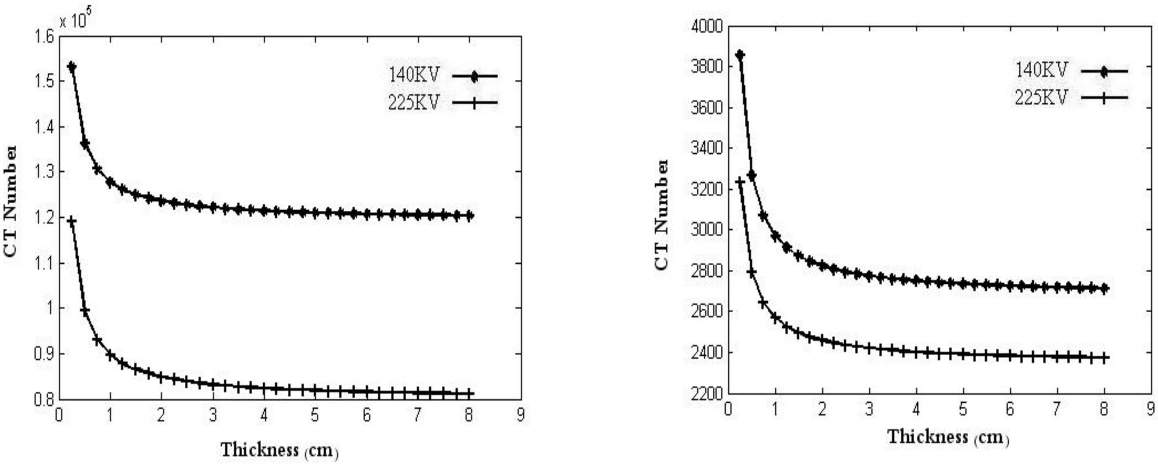
b: lead phantom

a: water phantom



c: aluminum phantom

Fig.2 Plot of attenuation factor at two energy 140 kv, 225 kv for a: water phantom, b: lead phantom, c: aluminum phantom



A: lead

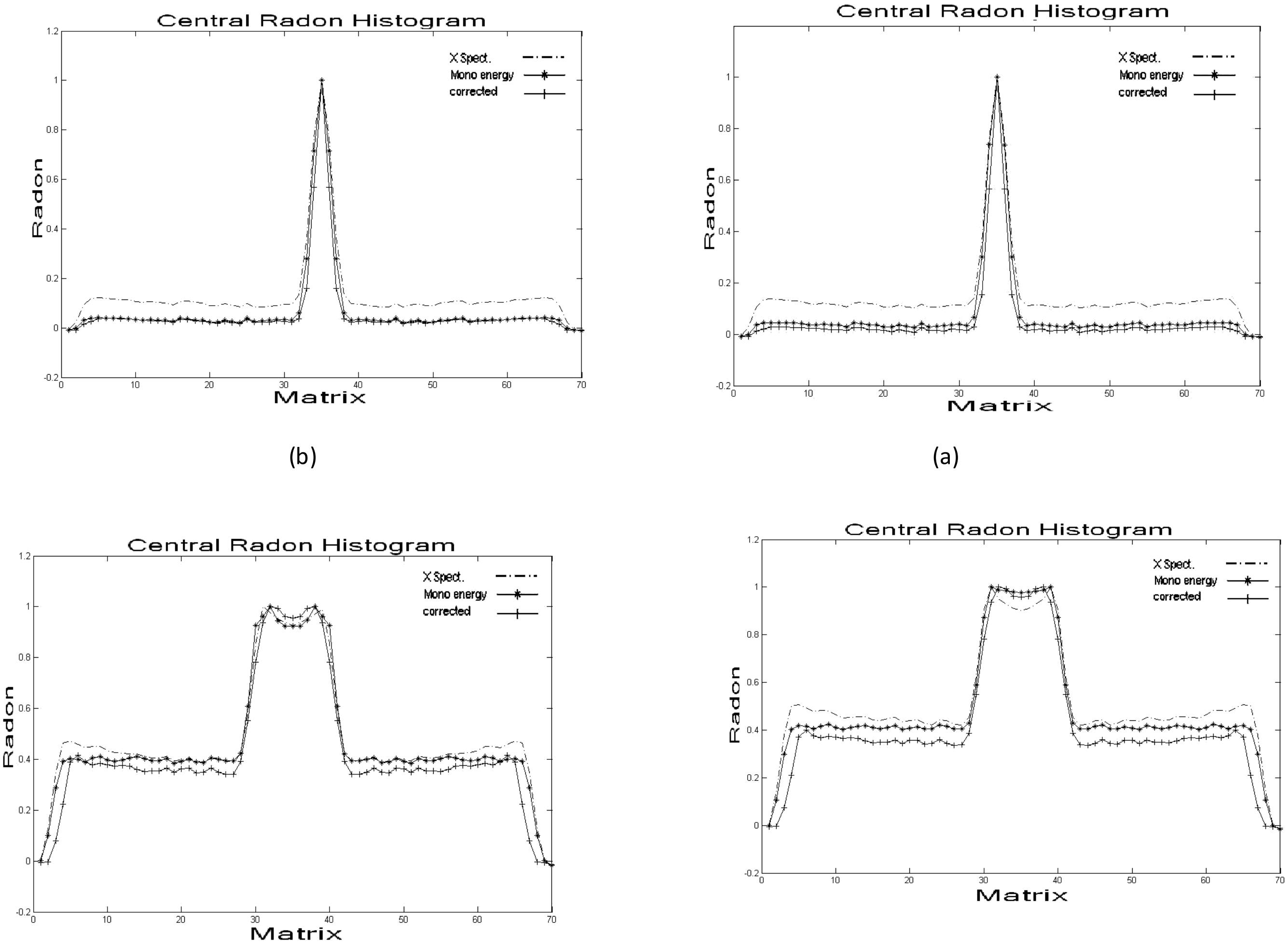
b: aluminum

Fig.3 CT number to thickness (cm) at two energy, 140kv, 225 kv for a: lead, b: aluminum

Reconstructed image due to 2 phantoms at 140 kv are showed in Fig 5&6.

Table- 1 Comparison between Radon output of X- spectrum and corrected X- spectrum to mono energetic source in lead-water phantom and aluminum- water phantom at 140 kv and 225 kv

	Lead-water phantom		Aluminum –water phantom	
	140 kv	225 kv	140 kv	225 kv
Radon error for x spectrum to mono energy	94.26	85.66	16.68	8.53
Radon error for corrected x spectrum to mono energy	33.15	17.40	6.30	3.43



(b)

(a)

Fig.4 Comparison between Radon output of X- spectrum profile, mono energetic source and corrected X--spectrum that normalized, a: lead- water phantom at 140 kv, b: lead- water phantom at 225 kv , c: aluminum- water phantom at 140 kv, d: aluminum- water phantom at 225 kv

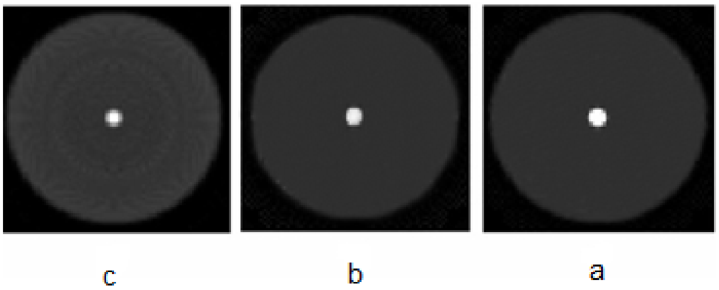


Fig.5 Reconstructed image of lead-water phantom at 140 kv for a: mono energetic source b: corrected X- spectrum, c: X- spectrum

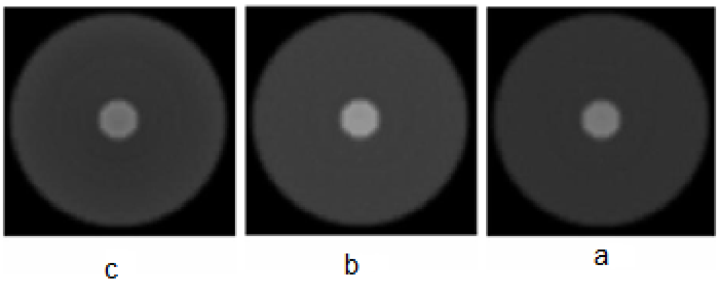


Fig.6 Reconstructed image of aluminum-water phantom at 140 kv for a: mono energetic source b: corrected X- spectrum, c: X- spectrum

4- DISCUSSIONS

Table- 1 shows that at low energy and high atomic number the beam hardening is high. Materials that used in industrial have high atomic number thus it is necessary to correct output data. By increasing energy beam hardening reduce but for heavy materials such as lead at high energy beam hardening is high. For example by increasing energy errors reduce from 92.26% to 85.66% that is high and need correction method.

For lead-water phantom at 140kv different between x-spectrum and mono energetic source is 92.26% after correction performance this difference reduce to 33.15%. At 225 kv for this phantom errors reduce from 85.66% to 17.40%.

For aluminum- water phantom at 140 kv errors reduce from 16.69% to 6.30% and at 225 kv errors reduce from 6.30% to 3.43%.

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