

Simulation an industrial CT with x-ray tube for 140 kv energy by MCNP4C code

* B. Azadbakht , A. Sahebhasagh and K. Adinehvand

Department of Engineering, Borujerd Branch, Islamic Azad University, Borujerd, Iran.

ABSTRACT

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 industrial CT 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 used Monte Carlo simulation, in this simulation, parameters that affect Beam hardening for different materials and energy 140 kv is evaluated.

2-METHOD AND MATERIALS

In this study we used Monte Carlo code (MCNP4C) that is a general method, for simulation of CT hardware, processing data and for 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 different energy and objects. The second stage of this study is simulation of an industrial CT by MCNP4C code for mono energetic source and an x-ray tube, in third stage output profile of industrial CT with x-spectrum is corrected by a correction algorithm.

Simulation of x-ray tube

For simulation filman, electron source and electric field we used a disc source with 0.05 cm radius in direct of anode, radius of disc source show focal spot of x-ray tube that here is 0.05 cm, schematic diagram of x-ray tube has shown in Fig. 1.,

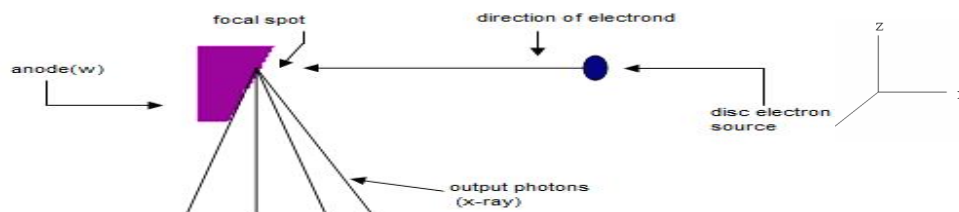


Fig. 1 schematic diagram of x-ray tube

*Corresponding Author: B. Azadbakht, Department of Engineering, Borujerd Branch, Islamic Azad University, Borujerd, Iran.
Email: azad_bakhtiar@yahoo.com

In this simulation, anode is from tungsten with 18.9 g/cm^3 density that thicknesses are in x direction is 2 cm and y and z directions are 1.5 cm, and angle of anode is 18° . In this study we simulated x-ray tube for 140 kv.

Phantoms

Simulated phantoms are cylinders that have various dimension and different materials. Thickness of phantoms is proper to half value layer at assumed energy. All phantoms are at 20 cm distance from x-ray tube.

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. For example two phantoms showed in Fig 2, 3,

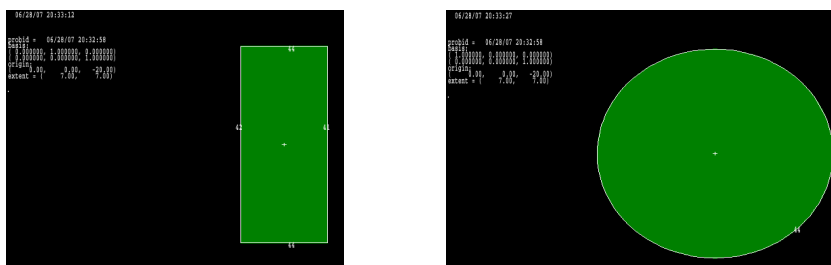


Fig. 2 water phantom a: PY=0, b: PX=0

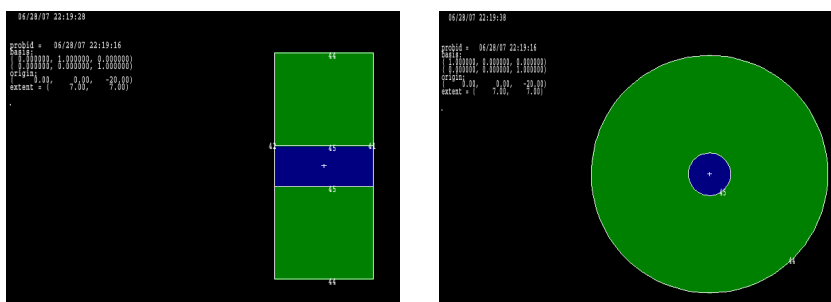


Fig. 3 water-aluminum phantom a: PY=0, b: PX=0

Position of detectors and how to acquisition data

For calculation of effective attenuation factor for different phantom and various energy, detectors are arranged in a direct line in phantom with distance 0.0025 cm from each other and once again them set in same position without phantom, you can see them in Fig.4, for 0.140 Mev in section between 0.00005 to 0.145 Mev, the output photon in each section calculated,

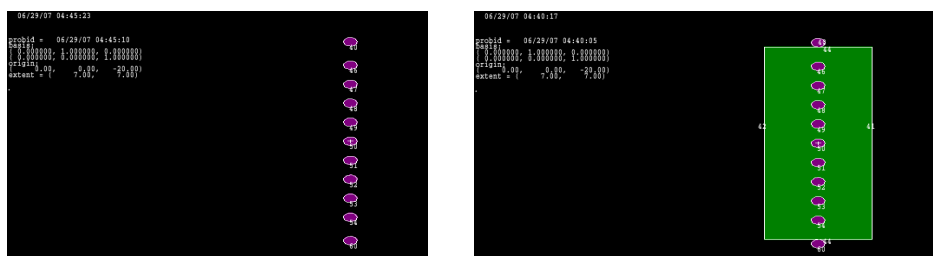


Fig.4 schematic diagram of detectors for calculation of effective attenuation factor
a: water phantom b: without water phantom

Now the x spectrum of 140 kv sees in MCNP4C space, Fig.5.

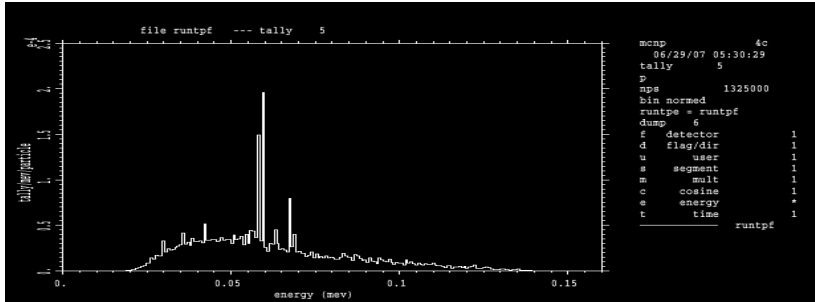


Fig.5 output x spectrum of 140 kv in MCNP4C space

F5 tally in outputs files show all photons and also uncollided photons for each section of energy, after acquisition of data in this section for all phantoms we can plot effective attenuation factor diagram for different energies. In next stage detectors arranged as an arc, out of phantom such as third generation industrial CT, Fig. 6.

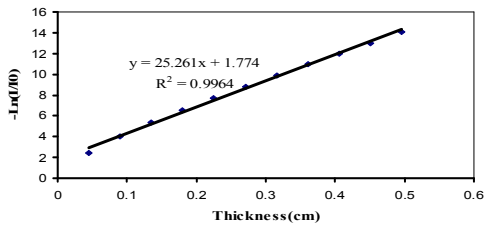


Fig. 6 a:detectors and alimiunim water phantom b:detectors in near vieiw

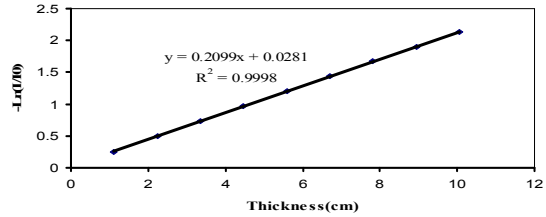
In this state center detector placed at 0° angle, detectors are at 25 cm distance of center of phantoms and 45 cm from focal spot. In this study a x- spectrum with 140 kv , is simulated. For various energy, we can use aluminum filters with different thickness. 75 detectors in form of an arc as a real CT are simulated; for all phantoms, data are got by f5 tally.

Calculation effective attenuation factor $\mu(\text{eff})$

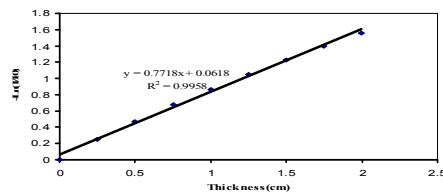
Effective attenuation factor $\mu(\text{eff})$ is slop of plot $\ln I/I_0$ to thickness. For calculation effective attenuation factor $\mu(\text{eff})$, it is necessary to acquisition X- tube output for various thickness. For each point in plot $\ln I/I_0$ to thickness, program ran for with phantom and without phantom states at same



b: lead phantom



a: water phantom



c: aluminum phantom

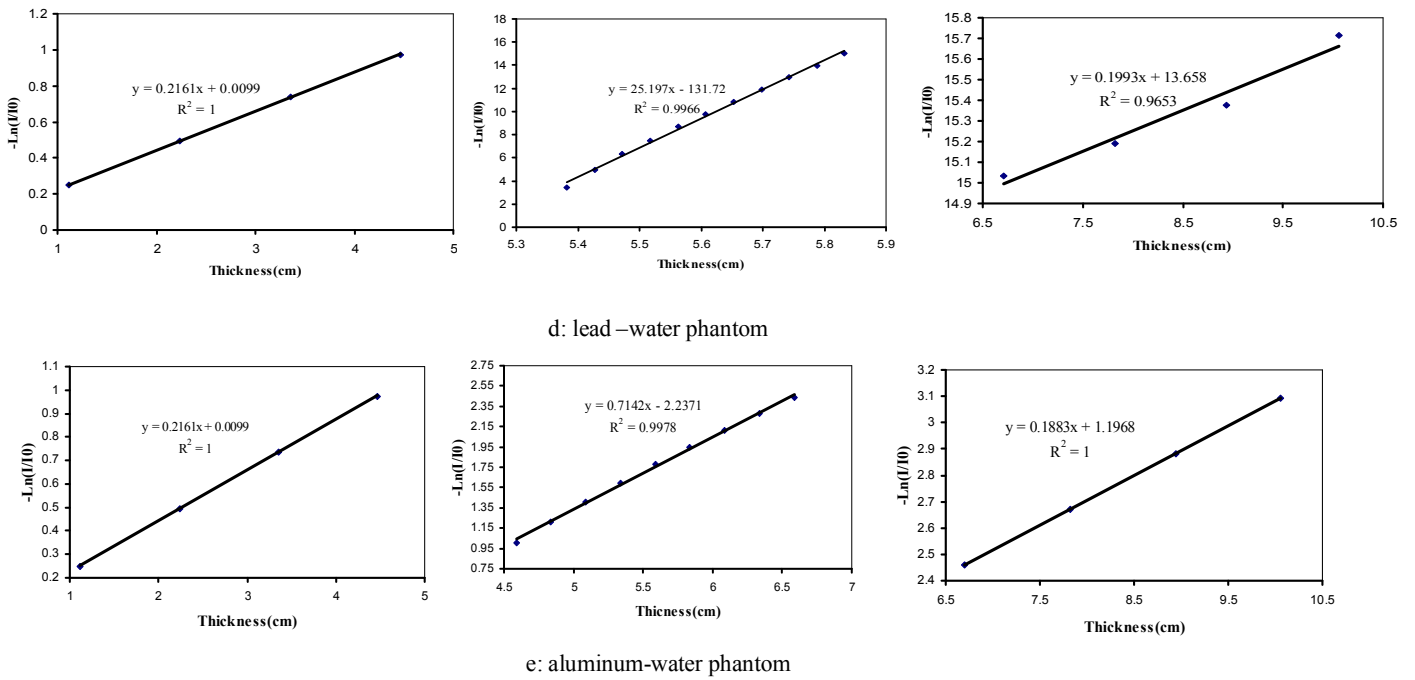


Fig.7 Plot of attenuation factor for energy 140 a: water phantom, b: lead phantom, c: aluminum phantom d: lead- water phantom, e: aluminum-water phantom

CT number calculation for two energy 140 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 acquire CT number from relation 1.

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

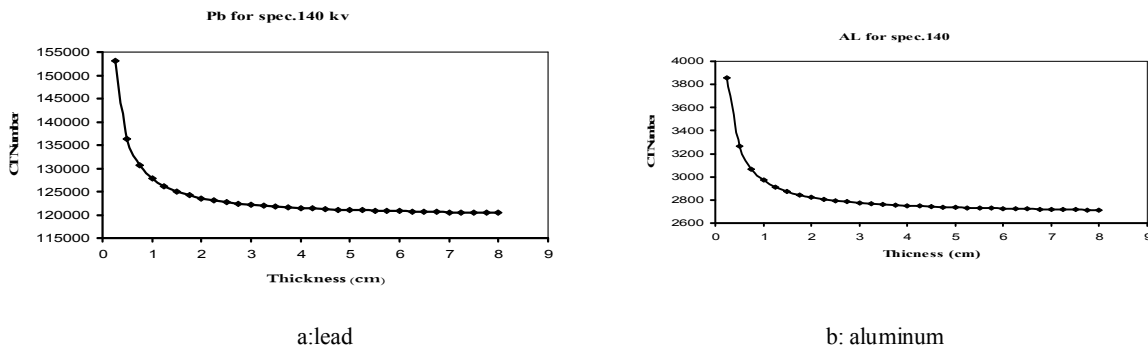


Fig.8 CT number to thickness (cm) for energy, 140kv, for a: lead, b: aluminum

Correction Algorithm

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

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

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 bellow Algorithm.

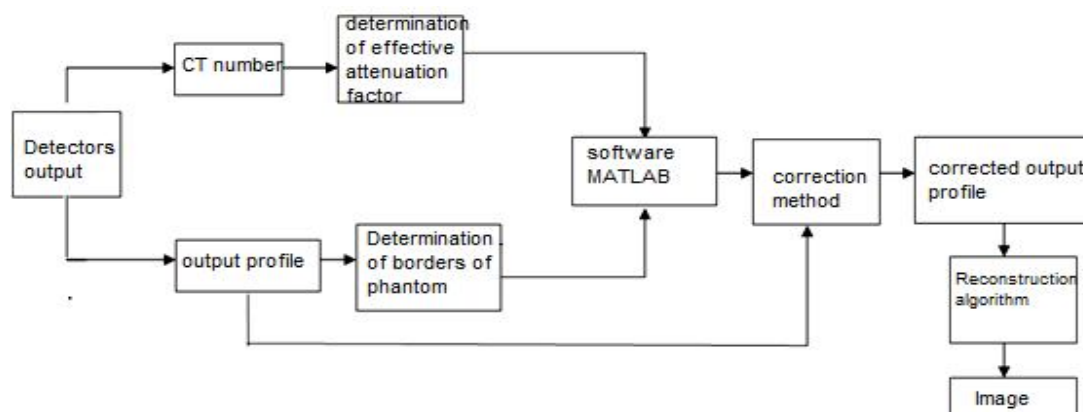


Fig.9 Correction Algorithm for image processing

3-RESULTS

Results due to attenuation factor for 2 phantom and CT numbers of lead and aluminum are showed in Table.1. Radon outputs of X- beam profile, corrected X- beam that normalized are showed in Fig.9 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.

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

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

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

	Lead-water phantom	Aluminum-water phantom
Radon error for x spectrum to mono energy	94.26	16.68
Radon error for corrected x spectrum to mono energy	33.15	6.30

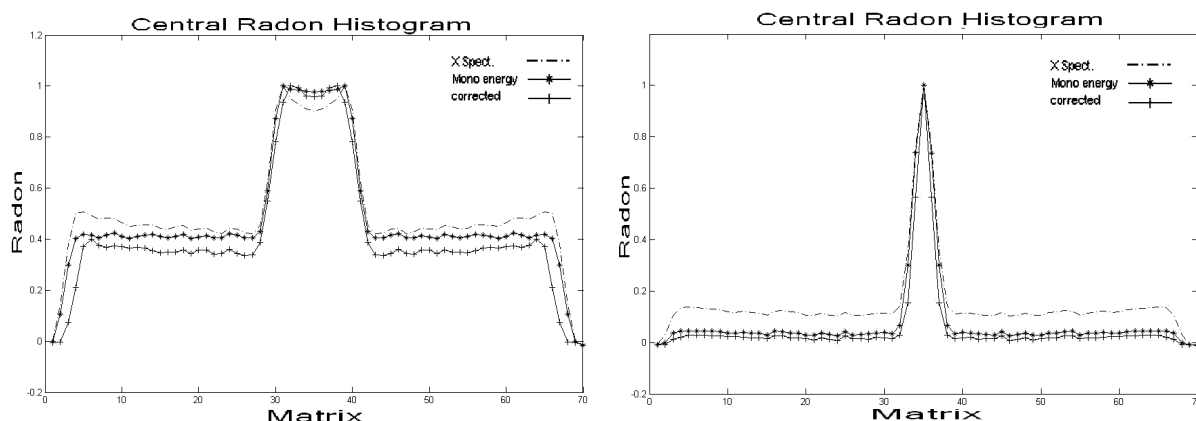


Fig.9 Comparison between Radon outputs of X- spectrum profile, mono energetic source and corrected X--spectrum that normalized, a: lead- water phantom at 140 kv, b: aluminum- water phantom at 140 kv

4-DISCUSSION

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 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%.

For aluminum- water phantom at 140 kv errors reduce from 16.68% to 6.30%

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