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A THIRD GENERATION GAMMA-RAY INDUSTRIAL COMPUTED TOMOGRAPHY SYSTEMS FOR PIPELINE INSPECTION

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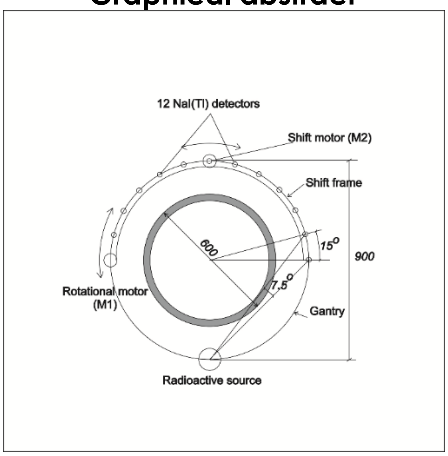
Graphical abstract



Abstract

This paper introduces an industrial CT system of compact fan beam configuration which was designed and fabricated by Centre for Applications of Nuclear Technique in Industry (CANTI) for inspecting pipe and small scale industrial equipment. The system utilizes a Cs-137 or Se-75 isotopic source. The source is contained in a fan beam collimator made of lead. The slit size of the source collimator is 10 mm in width in the axial direction and the opening angle of the fan beam is 90^0. Twelve ½ inch x 1 inch NaI(Tl) scintillation detectors and multiple SCAs (Single Chanel Analyzer) are used to set up the detection system. Filtered Back Projection (FBP) and Expectation Maximization (EM) algorithms were used for reconstruction of CT images. Having compact configuration of third generation CT, the size of gantry is 900 mm which enable to scan an object with diameter of 600 mm whereas the detector arc in a conventional third generation configuration must be at least 1200mm to cover the same object.

Keywords: CANTI, computed tomography, compact third generation CT system, pipeline inspection

1.0 INTRODUCTION

Computed tomography (CT) is an advanced technique that has been continuously developed and used for diagnostic purposes throughout last 40 years not only in medicine but also in industry, biology and civil engineering. During the past 5 years, Centre for Applications of Nuclear Technique in Industry (CANTI) has successfully designed, developed and fabricated the GORBIT, first generation industrial CT equipment with one gamma source – one gamma detector configuration. The equipment is portable, easy to operate, user friendly software [1]. The equipment had been used for investigating several simulated specimens as well as real industrial objects. The system had provided solutions to some problems in real cases which were not possible with conventional techniques such as radiography, ultrasonic testing. However, the scanning method applied for this equipment is very time consuming, which is not suitable for field applications [2].

We have developed a third generation CT scanner with compact detector arc where the center of arc is located in the middle of gantry. Hardware configuration is described in Section 2, reconstruction of CT image is introduced in Section 3 and some results of experiment are presented in Section 4.

2.0 THE COMPACT THIRD GENERATION CT SCANNER FOR PIPING INSPECTION

2.1 Hardware Description

Figure 1 shows a proposed design of a third generation CT scanner. This proposal has 12 radiation detectors which are arranged equiangular in an arc of 1200 mm radius and 600 angles to cover a specimen with maximum diameter of 600 mm. During a single projection, the detector arc can rotate whereas the source stands still in order to collect more ray. With this design, the scanning time is reduced from 2 to 10 times as compared with the single source – single detector CT system. However, the gantry is still cumbersome which is very difficult to apply in the field.

Figure 2 shows the innovated design of a third generation CT scanner. This proposal also uses 12 radiation detector sized ½ inch x 1 inch arranged in half of a ring with diameter of 900 mm. Radiation source is installed in the same ring at opposite side with detectors. The detector arc is allowed to rotate whereas the source stands still which is enable to get more ray for a projection. Pinhole collimator for detector cannot apply in this case so that panoramic disk type collimation is used. This design will lead to significant artifacts that require a corrective procedure.

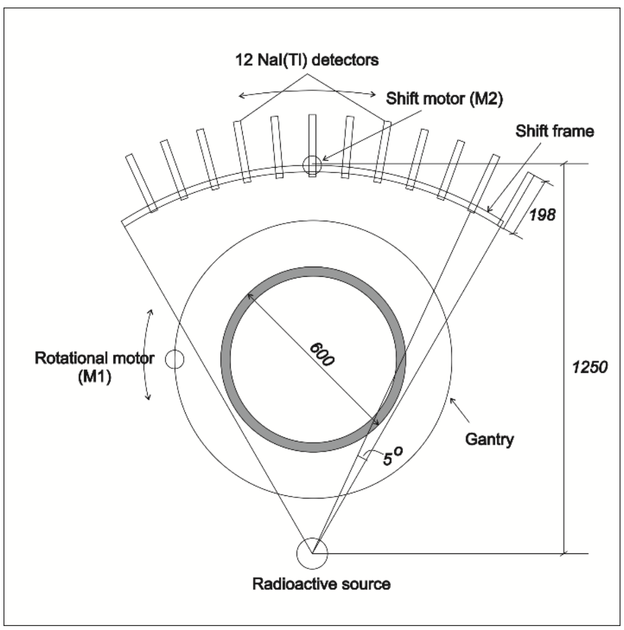


Figure 1 Conceptual design of third generation CT scanner

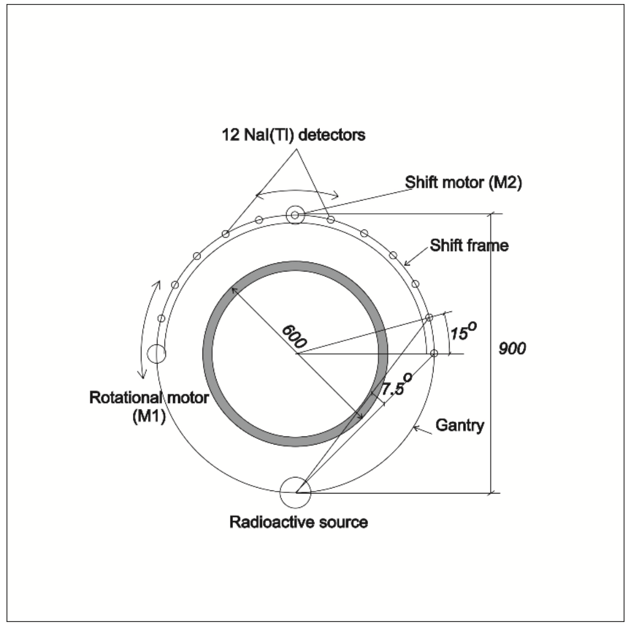


Figure 2 Innovated design of a third generation CT scanner

2.2 Motion Control and Data Acquisition System

Twelve NaI (Tl) radiation detector sized ½ x 1 inch operated by Ludlum model 4612 counter for acquiring data were used. The 4612 counter is a twelve detector SCA (single channel analyzer) with PC control of all necessary operating parameters. Up to twelve detectors may be connected to the counter each with independent high voltage, threshold or sensitivity, and window settings. The Counter is configured with a host board and up to 12 slave boards. The host board collects the counts from each slave board and communicates with the computer. The host board has an RS-232 connector for communicating with a computer. The slave boards are responsible for powering the detector and sending the count data to the host board. The Model 4612 Counter software monitors the activity of the Counter. The software allows the user to control and log data from individual channels or groups of channels. The software also allows the user to modify the parameters of each slave board.

Figure 3 describes the conceptual drawing of motion control and measuring systems. The scanning process is driven by two powerful stepper motors (M1, M2). The rotational motor M1 is used to rotate whole gantry around the object. The intermediate motor M2 drives the detectors step by step within the detector arc. The equipment has 4 optical sensors which are used for motion control. This motion system is controlled by a microprocessor via a visual basic program. The motion control program is combined and synchronized with a self-developed data acquisition program in a same PC interface that is easy to set up and operate. Figure 4 shows the 3D view of the equipment.

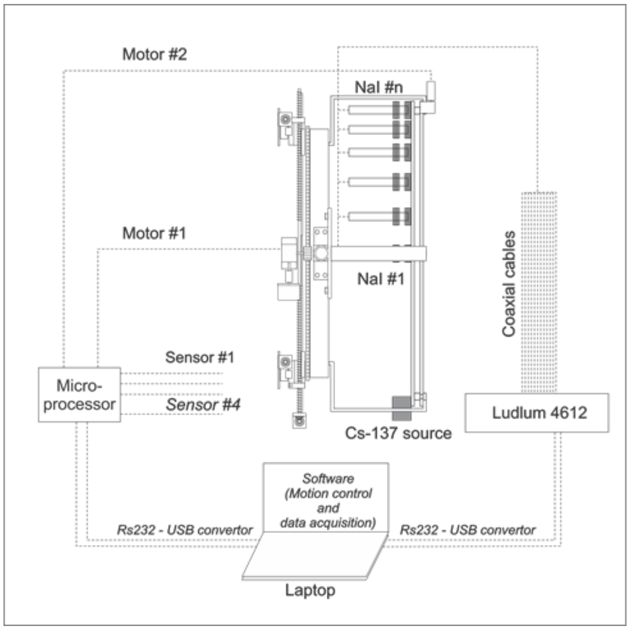


Figure 3 Motion control and data acquisition system

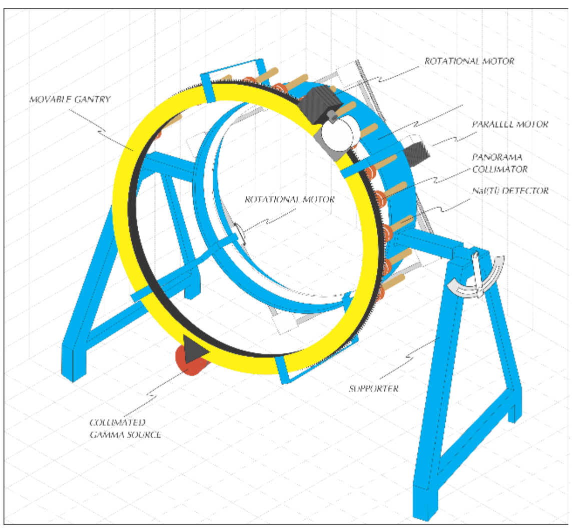


Figure 4 3D drawing of the innovated 3rd generation equipment

3.0 IMAGE RECONSTRUCTION

Figures 5 and 6 describe the projective geometry applied for parallel beam and fan beam, respectively. The Radon transform for each case is expressed as following.

3.1 Parallel Beam Geometry

$$P_\theta(t_1) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\delta(x.\cos\theta + y.\sin\theta - t_1)dx.dy \qquad (1)$$

Where

$$t = x.\cos\theta + y.\sin\theta$$
$$s = -x.\sin\theta + y.\cos\theta \qquad (2)$$

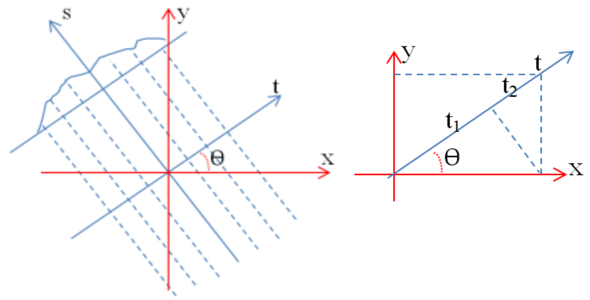


Figure 5 Parallel beam geometry

3.2 Fan Beam Geometry

$$P(\beta,\gamma) = -\ln\left(\frac{I_\beta(\gamma)}{I_0}\right) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mu_{(\gamma,L)} d_l.d_\gamma \qquad (3)$$

Where

$$L(x,y,\beta) = \sqrt{[D + x.\sin\beta - y.\cos\beta]^2 + [x.\cos\beta + y.\sin\beta]^2} \qquad (4)$$

$$\gamma = \tan^{-1}\left[\frac{x.\cos\beta + y.\sin\beta}{D + x.\sin\beta - y.\cos\beta}\right] \qquad (5)$$

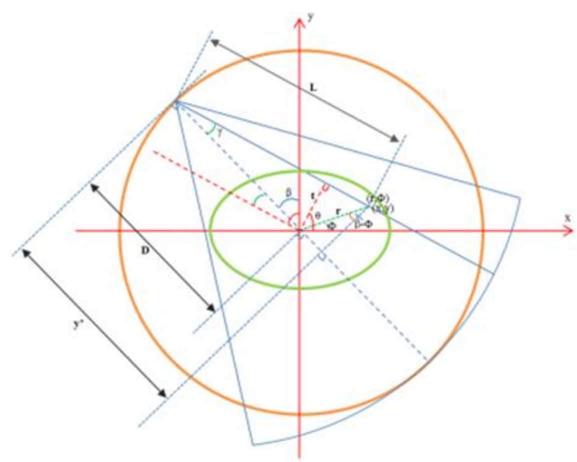


Figure 6 Fan beam geometry

Tomographic images are reconstructed from the combination of projected data (sonogram) by using analytic and iterative algorithms [5]. Each algorithm has their own advantages and disadvantages. The FBP algorithm delivers a fast reconstruction for a large number of projections whereas the iterative reconstruction is very time consuming. However, the iterative algorithm provides a best solution where the number projections are limited, especially in field applications. The same explanation can be found in [3].

The developed image reconstruction software for this equipment employed Filtered Back Projection (FBP), Algebraic Reconstruction Technique (ART) and Expectation Maximization (EM). Experimental CT images are shown in the next chapter.

4.0 IMAGE RECONSTRUCTION

Experiments were conducted on several kinds of specimens. Cs-137 isotopic source (0.05 Ci) was used. The first experiment was carried on a paraffin phantom with specifications shown in Table 1 and Figure 7. Figure 8(a) is the tomographic image and histogram obtained by the first generation configuration of CT system. Figure 8 (b) and 8 (c) are tomographic images and histogram obtained by the fan beam configuration with 240 rays/256 projections and 480 rays/256 projections.

Table 1 Specifications of the paraffin phantom

D (mm)	H (mm)	D/8 (mm)	D/16 (mm)	d1 (mm)	d2 (mm)	d3 (mm)	d4 (mm)
400	200	50	25	42	34	27	21

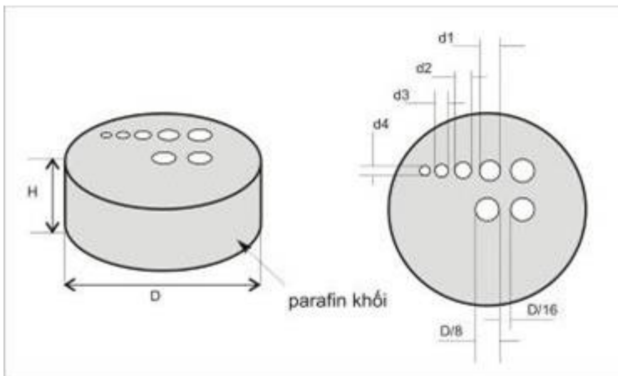


Figure 7 Paraffin phantom

For quantification of the results three error specifications were employed, which seem to be developed as some sort of standard [4]:

1. Reconstruction error:

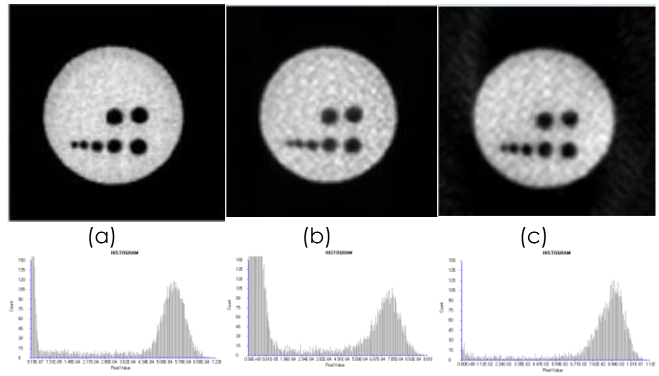
$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad (6)$$

2. The Root Mean Square Error with respect to N:

$$RMS_N = \sqrt{\frac{\sum_{i=1}^{n}(\mu_{t,i} - \mu_{tt.i})^2}{N^2}} \quad (7)$$

3. The Root Mean Square Error with respect to μ:

$$RMS_\mu = \sqrt{\frac{\sum_{i=1}^{n}(\mu_{t,i} - \mu_{tt.i})^2}{\sum_{i=1}^{N}\mu_{true,i}^2}} \quad (8)$$



σ = 5.6 %, RMS_N = 5.07E-3, RMS_μ= 6.35E-2	σ = 8.1 %, RMS_N = 6.68E-3, RMS_μ= 7.95E-2	σ = 6.6 %, RMS_N = 6.15E-3, RMS_μ= 7.23E-2
(a) Parallel beam 128 rays + 128 projections	(b) Fan beam 360 rays + 128 projection	(c) Fan beam 480 ray + 128 projections

Figure 8 Tomographic image and its histogram

The second experiment was carried with a mocked-up pipe with some strange material inside the pipe. Data were taken with 480 rays and different number of projection. The total measuring time were calculated and confirmed by experiment are shown below:

$$T(h) = N_{view}(M_{itv}.t_d + M_{itv} + t_{Rv} + t_v)/3600 \quad (9)$$

Where: T(h) is the total measuring time, hours; N_{view} is th number of projection; t_d is dwelling time, s; M_{itv} is number of intermediate rotation of detector arc; t_{Rv} is the reverse time of the intermediate motion; t_v is the rotation time from projection to next projection. Table 2 shows the calculated and experimental total measuring time for a number of tests.

Table 2 Measuring time vs. number of ray, projection

N_{view}	t_d	M_{itv}	t_{Rv}	t_v	*T(h) (calculated)*	*T(h) (experiment)*
256	0.5	40	4	4	4.84	4.52
180	0.5	40	4	4	3.40	3.25
128	0.5	40	4	4	2.42	2.20
128	0.5	10	4	4	1.35	1.20

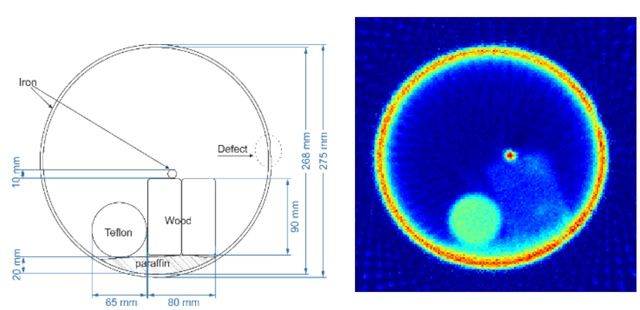


Figure 9 Tomographic image the mocked-up pipe

The third experiment was aimed to determine any blockage inside heat exchanger tube. A mocked-up heat exchanger tube was fabricated where some tube were filled with paraffin. The obtained CT image clearly shows the blocked tubes, as shown in Figure 9 and Figure 10.

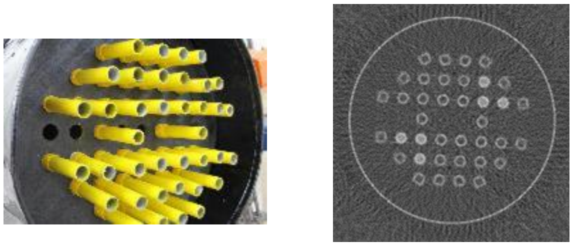


Figure 10 Tomographic image of the mocked-up heat exchanger tubes

5.0 CONCLUSION AND FURTHER PLAN

Centre for Applications of Nuclear Technique in Industry (CANTI) has developed successfully third generation computed tomography equipment for piping inspection purpose. Having compact gantry, the equipment has proven its possibility to apply in the field. The equipment has an advantage about measuring time over the first generation system, the image quality is good enough for piping inspection such as defect qualification; material built-up, blockage measurement or insulation investigation. Much research has been performed for improving the image contrast such as applying correction for radiation scattering, dual energy discrimination or improving the spatial resolution by using smaller size detector, high stopping efficiency such as LYSO detector. With the successful of the first generation CT system named GORBIT, we need to speed up the improvement on the equipment in order to introduce the second commercial industrial CT equipment of CANTI in near future.

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