IEEE Nuclear Science Symposium
Medical Imaging Conference

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IEEE

NUCLEAR & PLASMA SCIENCES SOCIETY

MIT Massachusetts Institute of Technology

NSS MIC 2010 Knoxville

2010 Conference Record

Knoxville, Tennessee, 30 October - 6 November 2010

Guest Editor: Klaus Ziock

IEEE Catalog Number: CFP10NSS-CDR

ISBN: 978-1-4244-9104-9 • ISSN: 1082-3654

Development of a Fourth Generation Industrial Tomography for Multiphase Systems Analysis

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***Abstract* – In the present work a 4D (three dimensions combined with the time) fourth generation CT system was developed with several detectors (as much as required) made with CsI (Tl) size of 5 mm x 20 mm width x length) coupled to PIN photodiodes size of 5x5 mm^2. It was also developed a pulse sensitive preamplifier in a small electronic circuit board with size of 9.5x100 mm^2 (width x length). This system was able to identify 80 keV photopeak at room temperature and was obtained a photo peak counting efficiency around 33% for ^{137}Cs. The proposed CT was assembled on a wooden platform, where the cylindrical detectors (photodiode + preamplifier + CsI (Tl) crystal) are arranged in pentagonal parallel or fan sectors. Five sources of ^{137}Cs or jointly with ^{133}Ba or ^{192}Ir are assembled at the vertices. Each detector was supplied with three power supplies: +12V,-12V and adjustable high voltage HV (capable to range from 0 to 2000V). The pre-amplifier signal was connected to a data acquisition unit containing amplifier, counter unit and transfer data via USB-2 cable to a computer type PC-Windows. The system was easily adaptable to the environment of the industries and able to produce multi-phase analysis in real time.**

I INTRODUCTION

The industrial distillation systems involve fast dynamic processes; in addition, they contain solid, liquid and gas mixtures. The distillation columns are usually built with steel and have large diameters and thicknesses that make their analysis unfeasible with conventional X-ray beams [1,2,3]. For this reason, gamma radioactive sources in the energy ranges of 317 keV (^{192}Ir), 662 keV (^{137}Cs) to ~1250 keV (^{60}Co) are preferable, instead of X-ray sources [4]. While for the medical tomography the patient is put inside the CT to be measured, for industrial applications the object (pipe or column) should be transported up to the CT system and, mechanically, adapted to the object environment. In addition, tomography system should be adapted to the different size of objects that are usually sited in a hostile environment (Fig 1),), containing flammable superheated materials, occasionally subjected to high internal pressure and presenting many difficulties for placing CT devices around these objects. Besides, the phenomena related to multiphase processes are usually fast, requiring high time resolution performance in the CT data acquisition. Besides this aspect, the density differences of each phase (solid, liquid and gas mixtures) recommend that the system of data acquisition be fast, with capacity to discriminate different energy levels (multichannel capability). Despite this evidence, nowadays most scanners are employed as lab equipment, in order to study and to optimize column designs and industrial processes (Fig. 2), as it can inferred from literature [1,2,5].

Fig. 1 – Typical industrial process columns.

In practice, these devices are not suitable for use in industrial plants. In such case, ideally, the tomography system should be fixed and not need to move their sources and detectors around the object. Additionally, a iCT system should be light enough to be easily moved and installed. Their detectors should operate at low voltage, being well-built and expected not to spark. In this context, HJERTAKEE et al. [6] developed a CT system that meets most of these requirements, to analyze a distillation column around 20 cm in diameter. The system consists of fixing 85 semiconductor CZT detectors (10x10x2 mm), divided into five sections containing 17 detectors/section and 5 sources of ^{241}Am, placed diametrically opposed to the five sections of the 17 detectors. HJERTAKEE et al [6] have discussed deeply about the best algorithms to reconstruct the images on-line, simultaneously. However, this tomography system was designed with its 85 detectors welded

Fig 2- Typical 3th generation CT used in lab for industrial objects design optimization.

Manuscript received November 27, 2010. This work was supported in part by the CNPq and IAEA.

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to a motherboard. This type of CT prevents the inclusion of new detectors and has lead collimators, relatively complex, what makes difficult to modify it in order to meet the needs of adaptation required in industrial environments. Besides, the use of 2 mm thick CZT detectors makes this tomography system ineffective for measurements that use ^{137}Cs or ^{60}Co radioactive sources.

This work presents a new iCT design that fits the requirements of an ideal iCT to analyze multiphase processes, in an industrial plant.

II. Material and Methods

The development of industrial CT scanner was guided to achieve a system that can be adapted with reasonable simplicity to the industrial structures and can be easily rearranged for future new configurations. Otherwise, it should have a fast electronic data acquisition capable to discriminate radiation energy levels.

Mechanical.

Fig. 3 shows two versions (parallel and fan types) of the iCT scanner proposed in this work.

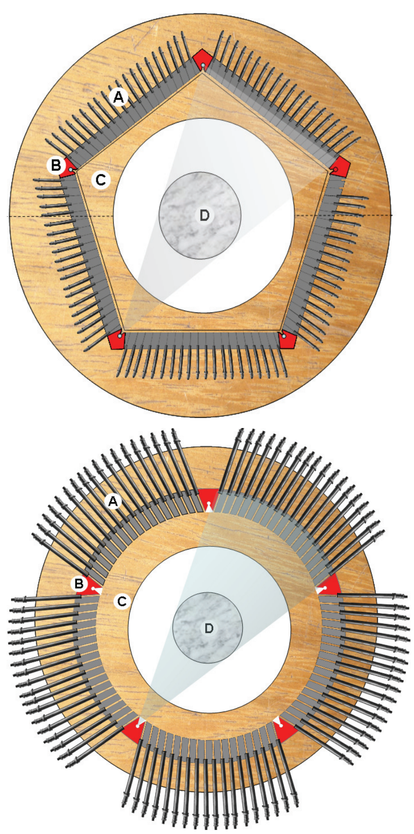

Fig. 3 - Two industrial tomography systems for multiphase analysis. CsI(Tl) detectors (A), collimators made with lead ingots (B), wooden platform or lightweight and strong material (C) and the multiphase object to be analyzed (D).

The iCT scanner is mounted in a disposable wooden platform which is cheap and light enough to be replaced in future applications. The system is made with lead collimators and the mechanical tool used to make it is basically a bench drill. The design of the collimator holes was previously drawn on a CAD program. A mask of the hole positions was printed on paper and pasted into lead ingot before the hurricane.

Detector and Electronics

The sensor used was the CsI(Tl) crystal coupled to PIN silicon photodiode (Fig. 4).

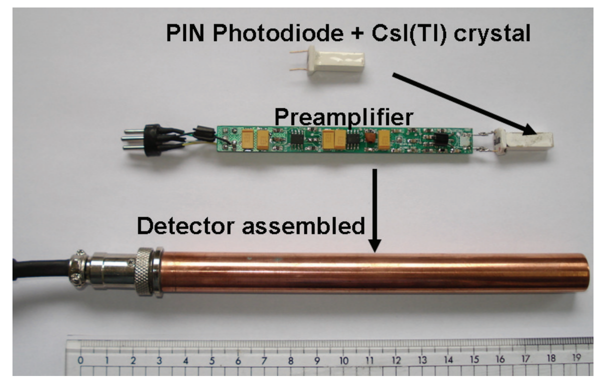

Fig.4 – Radiation detector components: CsI(Tl) crystal, silicon PIN photodiode, pulse sensitive preamplifier and final metal casing.

The preamplifier is basically composed of a low noise FET transistor (2SK152) and two operational circuit chips (LF356). The other components act as filters and decoupling voltages. The system is powered with +12V, -12V and a positive "HV" voltage in the range of (20 to 70V) applied to the cathode of the photodiode.

Following, the gamma-ray detector circuitry amplifies and filters the pulses emerging from the preamplifier stage of the detector circuitry. Short output pulses from this stage, i.e. in the order of 2 to 3 µs duration. This ensures high count rate capability allowing a maximum count rate of approximately 0.5×10^6 counts/s/detector for equally spaced pulses. The pulse height output is proportional to the detected energy photon.

The data acquisition system circuitry assembly consists of a MCA (Multi Channel Analyzer) (Fig.5).

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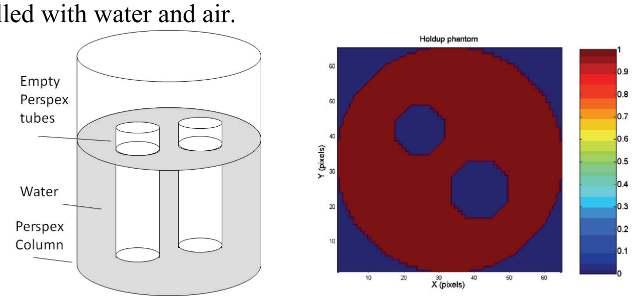
Fig.5 – Data acquisition system. In this board there is a HVsupply (0-2000V capacity), shaping and amplifier, signal sample-and-hold, ADC unit (8 bit resolution).

It consists of a high voltage module capable of powering the detector circuit up to 2000V, although for the PIN photodiode-CsI(Tl) detectors the HV do not exceed more than 70V. The detector signal is amplified, shaped (~ 2 µs), sampled-and-hold and digitized (ADC0820CCN, conversion time of 800ns). For each detection event a memory region (channel) is incremented by one. Each channel consists of three bytes, allowing up to 16777216 counts per channel.

Each data acquisition board is connected to a motherboard which in turn communicates with a PC computer via USB cable. Each motherboard supports up to 16 data acquisition board. For a tomography with 100 detectors it is necessary (100/16=6.25) seven motherboard. The threshold level is adjustable, independently, for each detector. Thus, the MCA comprises a rejection facility of low energy photons, which will reduce the raysum error caused by background radiation and the photon scattering mechanism [7,8].

ALGORITHM

The alternative minimization algorithm (AM) was used since it represents a good compromise between convergence rate and accuracy as demonstrate by MAAD [8] The images were generated using 65x65 grid with 1cm spatial resolution. The 4D-CT system with five ^{137}Cs sources and 90 detectors fan-beam geometry was validated studying a physical model showed in Figure 6. This phantom was built as a large multiphase gas-liquid system column (50 cm diameter) and filled with water and air.



(a) (b)

Fig. 6- (a) Phantom consists of a short column section filled with water and two small empty tubes (air). Perspex was used because creates low attenuation. (b) Ideal water holdup distribution, when the maximal value (one) on the color scale means 100% of water.

III. RESULTS AND DISCUSSION

The profile of signal processing in the data acquisition board can be inferred from Fig. 7. In terms of the pulse after the end of amplification, its time size is approximately 3µs and if the ADC conversion time is added, the total time will be approximately 4 µs. Also, the CPU processing time should be added. The 8051 CPU requires 19 Assembler instructions to perform the counts in the channel. Table 1 displays the time taken to perform one count in the memories of a 8051 CPU under a clock 40MHz. As it can be observed, the required time depends on the number of total counts already present in the channel.

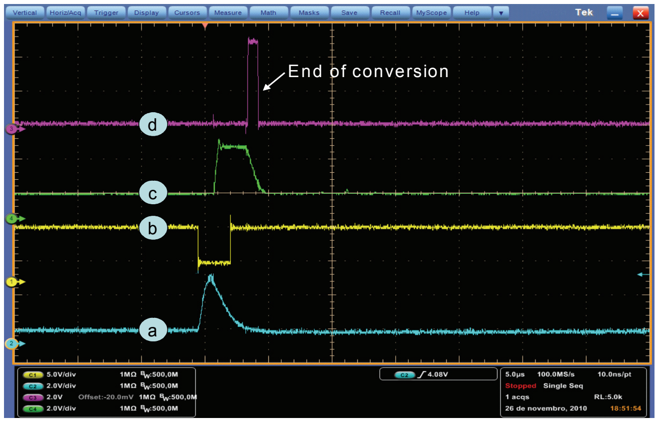


Fig. 7 – Signal profiles MCA (Multichannel analyzer). (a) input signalafter last amplification stage, (b) triggering sampling signal, (c) after sample-and-hold circuitry which is the signal that will be digitized by the ADC and (d) the signal that informs the CPU that the conversion had finished (at the fall edge).

TABLE I
Count processing time applied for a 8051 CPU at a frequency clock of 40MHz.

Time required to Processing a Count/Channel (µs)		
Counts Acumulated per Channel		
<256	256 to 65535	>65535
4.2	6.6	8.4

Considering: (1st) the maximal CPU processing time (8.4 ms), (2nd) the pulse shape (3 µs) and (3th) the ADC conversion time (0.8 µs), then, in the worse case, the system will require 12.4 µs to build up a count. This ensures high count rate capability, i.e. a maximum count rate of approximately $0.8\text{x}10^{6}$ counts/s/detector for equally spaced pulses, or on other words, it is equivalent to a sampling at a rate of 0.8 MHz. This sampling rate is considerable high and practically sufficient for the purpose of a scanner that uses radioactive sources. This sampling rate (0.8 MHz) is bit lower compared to that described by MAAD [8] (2 MHz), however, this is the price to have a system with the multi-channel analyzer (MCA) technology. The main advantage of having the MCA system is that it can use a combination of radioactive sources to explore more rigorously the densities difference from object. This aspect is crucial in multiphase processes. While higher energy radiations improve the image quality for solids, in opposite, lower energies are more suitable to study low density objects, like the gas mixtures. The combination of the CsI scintillator coupled to PIN diodes becomes possible to achieve energy resolution of approximately 7 to 15% [9]. The detectors used in this study, allow separating the energies from ^{137}Cs and ^{133}Ba sources, as shown from the Fig 8. This kind of detector is useful for tomography objects of size up to approximately ϕ 250 cm. As it can be observed from Fig. 3, as larger is the object, the detectors should be far from the sources. As it is known, the efficiency of counts decreases with the inverse square law [4]. Thus, small detectors are not suitable for large objects. In such case, it is suggested to use larger detectors.

The electronic system used in this work can be used for detectors coupled to photomultipliers.

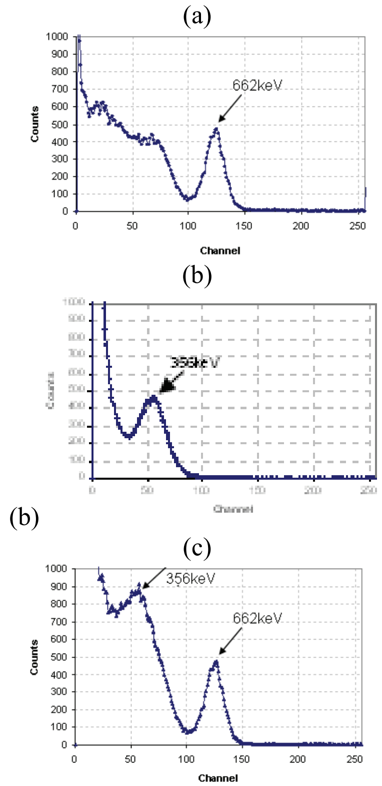


Fig.8 – CsI(Tl)-PIN photodiode spectra. (a) ^{137}Cs, (b) ^{133}Ba and (c) both sources together.

Figure 9 shows the holdup distribution reconstruction for gas and liquid. Is very important to notice that the CT system is static with only five views and 100 projections but with high temporal. The air "bubbles" profiles are clearly visible been possible differentiate water and air.

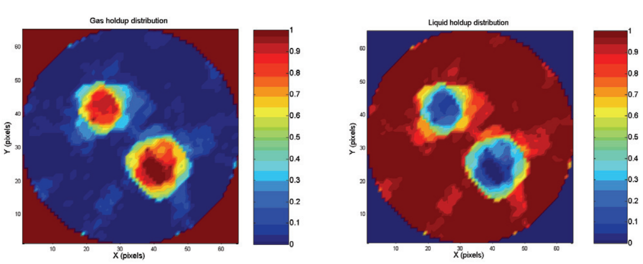


Fig. 10 - Gas and liquid holdup reconstructions in 65x65 pixel grids.

IV. Conclusion

In conclusion, the detector assembled with CsI(Tl) coupled to PIN photodiode showed suitable to measure two radioactive sources simultaneously. The system is light and easy to install in the industrial structures. The data acquisition system has fast speed to tomographic data acquisition and this real time CT scanner represents a powerful tool to study multiphase systems in-situ capable to obtain on-line data useful to control and optimization process.

Acknowledgment

The authors express their gratitude to CNPq – National Council of Scientific and Technological Development (Proc. CNPq 6202201/2008-8 and 308132/2009-2) and International Atomic Energy Agency – IAEA (AIEA-TC-BRA08/31) for the financial support.

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Nome do arquivo:	IEEE_2010_Proceeding.doc
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Título:	NSS-MIC 2006 Conference Record Template
Assunto:	
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Data de criação:	20/11/2010 17:20:00
Número de alterações:	40
Última gravação:	27/11/2010 12:54:00
Salvo por:	Home
Tempo total de edição:	1,725 Minutos
Última impressão:	27/11/2010 14:06:00
Como a última impressão	
Número de páginas:	4
Número de palavras:	2,298 (aprox.)
Número de caracteres:	12,413 (aprox.)