Flow Measurement and Instrumentation 47 (2016) 1–9

Contents lists available at ScienceDirect

Flow Measurement and Instrumentation

journal homepage: www.elsevier.com/locate/flowmeasinst

Industrial tomography using three different gamma ray

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ARTICLE INFO

Article history:
Received 10 November 2014
Received in revised form
23 August 2015
Accepted 2 October 2015
Available online 9 October 2015

Keywords:
Computed tomography instrumentation
Detector instrumentation
Gamma-ray attenuation
Multisource tomography
Multiphase industrial process

ABSTRACT

This study describes the development of a multisource computed tomography (CT) system that proved to be a useful tool to study multiphase systems. In this CT system, two different radioisotope sources, ^{192}Ir (317 keV and 448 keV) and ^{137}Cs (662 keV), were placed in a single lead collimator and several tomography measurements carried out. The multisource CT system was capable of determining as well as differentiating the attenuation coefficients of materials with two phases (gas and liquid). It was also able to provide important information concerning the hydrodynamics occurring inside a multiphase column.

1. Introduction

Multiphase systems are structures that contain a mixture of solids, liquids and gases inside a chemical reactor or pipes in a dynamic process. These systems are widely used by the chemical, food, pharmaceutical and petrochemical industries. The gamma ray CT system has been applied to visualize the distribution of multiphase systems, providing analysts and engineers the means to obtain measurements in real time without actually interrupting production. CT systems have been used to improve design, operation and troubleshooting of industrial processes. Computer tomography for multiphase processes is now a promising technique being developed at several advanced research laboratories [1–12].

Scanners for transmission tomography employ X ray or radioisotope sources positioned on one side of the object to be scanned and one, or a set of, collimated detectors arranged on the opposite side [5–7,12–14]. Currently, scanners typified as third [1,5,11,13,15] and fourth generations [3,16] are commonly used in industrial applications. Usually, the third generation CT systems have better spatial resolution [15], while gamma ray fourth-generation scanner systems characterized as static scanners have enhanced temporal resolution (time needed to obtain an image). Also it is capable of generating images at a faster rate but generally with lower spatial resolution on dependence of its lower number of detectors. On the other hand, if spatial resolution is an important needs and knowledge of dynamic phenomena can be limited to their trends, then third generation scanner systems should be a suitable choice [16].

Usually, the analyzed objects in the industrial tomography field, such as distillation columns and engines, contain materials with a large range of densities, for example iron (7.8 g/cm^3), aluminum (2.7 g/cm^3), water (1.0 g/cm^3), gases (0.000125 g/cm^3). Thus, ideally, radioactive sources containing different gamma energies should be used. The combination of ^{137}Cs with ^{192}Ir or ^{137}Cs with ^{75}Se could be used as their energy spectra present energy peaks of 662, 468, and 317 keV for a ^{137}Cs+^{192}Ir combination or 662, $\approx$132, $\approx$269 and 401 keV for a ^{137}Cs+^{75}Se combination. Moreover, in case the object to be analyzed contains high-density material, the ^{60}Co (1173 and 1332 keV) can be included in the source combination to allow the beam to cross the materials. However, depending on the density and dimension of the object the ^{241}Am (59 keV) can be added to the source combination in order to improve the image quality in the regions where low density material is present. Moreover, if the image details of the object edge are important for the analysis, thus photons with low energy are preferable because the path of radiation absorption in the object edge is relatively small [15].

CT systems measure linear attenuation coefficients, μ (cm^{-1}) which depends on material density. Generically, high-density material implies a reduction of the transmitted beam. According to the attenuation exponential law (Beer–Lambert's law), the fraction of a beam from high-energy radiation that crosses an object of high density is higher when compared to that low-energy radiation. This effect is caused by the decrease of the mass coefficient μ (cm^{-1}) as the energy of the radiation increases (see Fig. 7). Thus,

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http://dx.doi.org/10.1016/j.flowmeasinst.2015.10.001
0955-5986/

for objects containing different density materials, ideally, the tomographic measurement should be carried out, using different energies from gamma rays. In this case, the CT data acquisition system should have the ability to discriminate between different gamma ray energies. An arrangement with ^{192}Ir (≈ 317 and ≈ 468 keV), ^{137}Cs (662 keV) and ^{60}Co (1173 and 1332 keV) sources meets this need. Alternatively, depending on the density profile of the multiphase components, a single radioisotope source, such as ^{75}Se (≈ 132, ≈ 269 and 401 keV), could be used [15].

In order to analyze multiphase objects, some laboratories use two radiation sources positioned at 90 degrees to each other and two sets of detectors with their respective monochannel counters [17]. However, this option has the inconvenience of needing a double set of detectors and counters. Instead, fast multichannel counters with a only set of detectors can be used. This alternative meets the requirements of the CT system for multiphase system analysis more efficiently since the number of shielded sources, detectors and counters are reduced.

In this study, a third generation multi-source transmission computed tomography system with a multichannel data acquisition electronic system was developed. Two different radioactive sources, ^{192}Ir (≈ 317 keV yield = 87%; 468 keV yield = 48% and 604 keV yield = 8%) and ^{137}Cs (662 keV) were placed in a single lead collimation system. The capacity of this CT system to determine and differentiate the attenuation coefficients of materials with two phases (gas and liquid) was studied using different radioisotope energies and a bubble column (ϕint = 8 cm).

2. Equipment and experimental procedures

2.1. CT description and radioactive Sources

A third generation computed tomography system was developed for industrial applications at the CTR-IPEN [5,15]. In its configuration, an array of five NaI(Tl) detectors of 5×5 cm^2 (diameter, thickness) were placed on a gantry, in an arc, opposite the gamma ray sources (Fig. 1). The entire apparatus (gantry with detectors and gamma sources) rotated around the stationary object, by means of a stepper motor controlled by a host computer. The five NaI(Tl) detectors were individually collimated with lead. Each collimator had a hole of $2 \times 5 \times 50$ mm^3 (width, height, depth) for beam sampling. Two different radioactive sources, ^{192}Ir (12.2 GBq≡330 mCi) and ^{137}Cs (3.3 GBq≡89 mCi), were placed together into a radioactive source case and measured simultaneously in the tomography experiments. Fig. 2 shows the illustration of the multichannel modules device, whose electronic system (Fig. 2) contains up to 12 multichannel boards (8 bits resolution, 256 channels/board) each with its own individual high voltage (HV) supply and a circuit to control three step-motors. For this application, 256 channels/detector are enough and the ADC used presents high-speed conversion time (≈ 800 ns/ conversion).

Considering all the circuitry (Fig. 3), the total time necessary to processing a signal is 8.4 µs per incident photon [13,14]. For each channel, the accumulated count is stored in three bytes, thus each channel has a capacity to accumulate 16,777,216 ($2^{3 \times 8}$) counts/channel and 4,294,967,296 counts in the 256 channels. The speed of data acquisition was the main criterion used to design the described multi-channel analyzer. The electronic circuitry and the electronic pulse profile are shown in Fig. 3. A typical ^{192}Ir and ^{137}Cs spectrum is shown in Fig. 4.

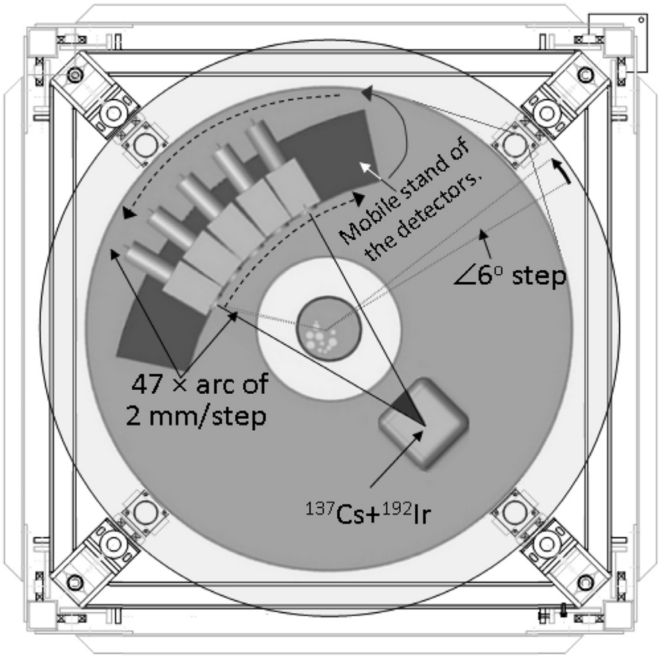

Fig. 1. Diagram of the third generation CT scanner used.

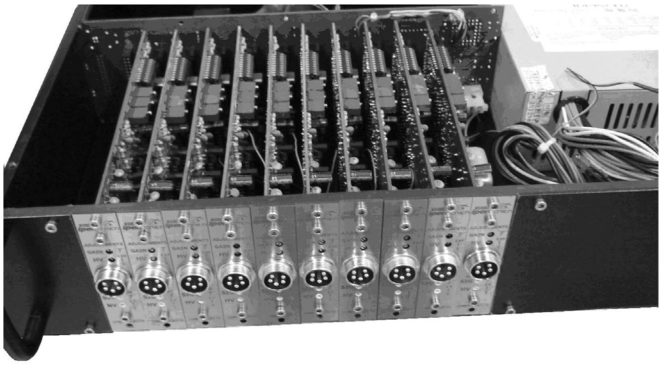

Fig. 2. The multichannel modules.

Before the tomography measurements, the five detectors were pre-adjusted using a ^{137}Cs source. The gain of each detector amplifier was adjusted in order to keep a similar spectrum profile for all detectors. After that, measurements for each detector were carried out, using two different radioactive sources (^{137}Cs and ^{192}Ir) separately. The spectrometric measurements were then performed, interposing lead absorbers, between the source and the detector set. Lead absorbers from 0 to 1.5 cm thick, were sequentially interposed in order to define the degree of spectrum overlap factors. After these preliminary adjustments, the ^{192}Ir and ^{137}Cs sources were placed together in a lead shield, and the combined spectrum was measured in order to select the counting windows, as shown in Fig. 5. For all windows, the counting levels were up to 10,000 counts/10 s to assure the measurement errors below of 1% (Poisson error = square root of counts). Tomography measurements were performed by 10 s/acquisition for each one of the 2820 measurements/detector per image. For each measurement, the count sum Σ_{Cs} of the channels contained in the ^{137}Cs peak window (120–160 channels) was calculated (Fig. 5).

This value was multiplied by the factors 0.28 and 0.31 for the fractional overlap spectrum of ^{137}Cs and ^{192}Ir in the 468 keV and 317 keV windows, respectively (Fig. 5). Finally, the counts of 468 keV ((Σ_{Ir468}) and 317 keV ((Σ_{Ir317}) windows from ^{192}Ir were subtracted from the contribution of ^{137}Cs.

2.2. Tomography measurements

A multiphase phantom was designed and prepared to evaluate