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A Review of Process Tomography Application in Inspection System

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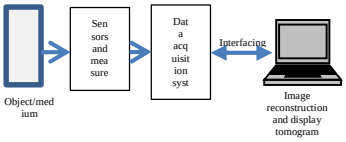

Abstract

The inspection system is crucial to ensure the system is always in a good condition. A technique that can be used for inspection system is process tomography. By promising non-destructive approach; various types of process tomography applied in civil, manufacturing and electrical applications. The purpose of this paper is to review the types of process tomography such as ultrasonic tomography, x-ray tomography, optical tomography, electrical resistance tomography, and electrical impedance tomography that had been applied to the inspection system. Variety techniques of inspection based on those sensors briefly discussed in this paper. The result showed that the process tomography expanded tremendously in the inspection system. Finally, a potential future research on the inspection system in the civil application proposed in this paper.

Keywords: Inspection system; process tomography; ultrasonic tomography; x-ray tomography; optical tomography; electrical resistance tomography; electrical impedance tomography

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1.0 INTRODUCTION

Inspection process is an approach that can be used to evaluate the medium measurement of structure or health. This process is imperative in many applications such as the detection of defect or cracks of the bridge, cement concrete, and pipelines. Based on the inspection process, it will help the system to be used for long term of the period with a low risk of damage. Otherwise, if there is no inspection done for a system, the system may face with problems. In other words, inspection process can be classified as part of quality control of certain systems.

One method that can be carried out in inspection system is the process tomography. Originally, the 'tomography' itself comes from the Greek word which 'Tomos' means a section and 'graphy' means image [1]. Alternately, the tomography can be a method to reconstruct the image of object's interest within the sensing zone [2]. Since 1970s, tomography was widely successfully carried out in medical applications. In decades of research, tomography had been also built in industrial use that is commonly known as Industrial Process Tomography (IPT) or only as Process Tomography (PT) [3]. Due to its main advantage which is non-destructive to the process or object being measured, it makes the process tomography become extensively researched in industrial applications.

Tomography system consists of three important parts which are; hardware part, interfacing, and software part as shown in Figure 1. The hardware part included the sensors, electronic measurement circuits and the transducer ring/plate of object/medium measured. Besides, the interfacing is usually referred to the data acquisition system (DAS) whilst the software part of image reconstruction and display the tomogram. Based on the different sensors, the types of process tomography used for measuring the object/medium interested. Consequently, the different types of process tomography work based on the different principle of sensors interested and performed in the applications. Thereby, based on the x-ray, ultrasound, optical radiation or electrical conductivity, process tomography can be performed for inspection system. Formally, the tomography can be divided into two fields that are hard field tomography and soft field tomography [4]. These classifications of tomography are referred to the natural behavior of sensors.

Thus, in this paper the review of applications of process tomography in inspection system within ten years is presented from year 2005 till 2014. Several types of process tomography that had been used for inspection system such as X-ray Tomography, Ultrasonic Tomography, Optical Tomography, Electrical Resistance Tomography and Electrical impedance Tomography discussed. Later, some potential future research application also stated in this paper.

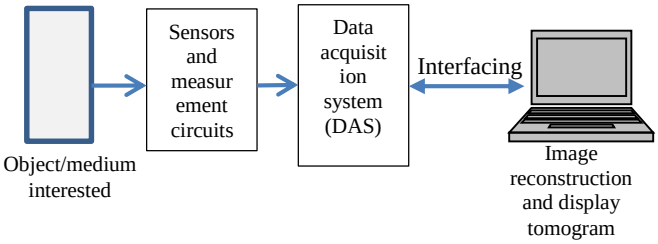

Figure 1 Basic block diagram of tomography system

2.0 INSPECTION SYSTEM BASED ON ULTRASONIC TOMOGRAPHY

Ultrasonic tomography (UT) reconstructs the image based on interaction between the ultrasonic waves (frequency of 20 kHz to 10 MHz) and the medium interested [5]. In civil application, UT successfully applied for concrete bridge and concrete construction inspection. For instance, Liu & Go [6] demonstrated the use of ultrasonic tomography for inspection the column bridge. In this system, the steel fiber reinforced in the concrete highway bridge had been used for the purpose of inspection. Based on MEDA-3B seismic data acquisition system, the seismic inspection was quite effective and credible to implement for identifying the condition of the concrete highway bridge. Moreover, UT also successfully used for detecting the corrosion and void in the post tensioned bridge [7]. The system was applying the ultrasonic C-Scan to overcome the deterioration in pre-stressing/ post-tensioned strand or tendon condition that is not always reflected by distress visible on the concrete surface. Figure 2 shows the block diagram of C-Scan imaging setup.

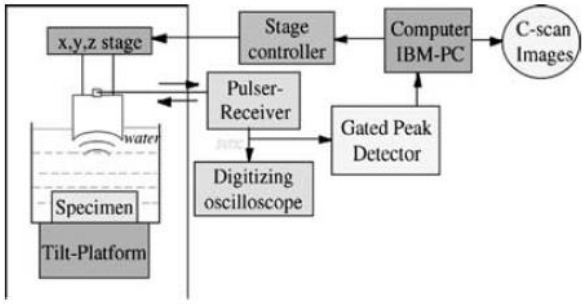

Figure 2 A block diagram of C-Scan Imaging setup [7]

Correspondingly, a work by Liu & Yeh [8] showed the use of vertical spectra tomogram to identify the internal crack of the concrete structure by using impact echo data. Here, three types of spectra tomogram: Fourier tomogram, the enhanced Fourier tomogram, and the local maximum tomogram focused. Different types of tomograms exhibit different attributes. The tomogram represented in this process can be used to estimate the size, depth and orientation of the crack.

Furthermore, Rodrigues *et al*. [9] progressively work on inspection of many flaws. Based on pulse-echo method, the ultrasonic inspection method was able to detect the many flaws. It improves the performance of precedent solutions thought for isolated flaw cases.

Nevertheless, a review paper by Sposito *et al*. [10] presented the ultrasonic techniques (based on velocity, backscatter and attenuation) that had been used to determine the creep damage in power plant steel. In this paper, different techniques of ultrasonic will cause a different result. The best method that can be applied for detecting the surface state was by using ultrasonic velocity, while ultrasonic attenuation process was not very good in identifying the crack and much research still needed if to perform the ultrasonic backscatter.

On the other hand, UT was implemented in chemical application for pipeline inspection. An inspection method of pipes with general bend angles, for example, by Verma *et al*. [11] successfully completed. Normally, it was quite critical to do an inspection with the curve area especially related with a small area of pipeline. Here, non-destructive method will help to identify any defect at bend angle of pipeline. Figure 3 shows the system that had been done by Verma *et al*. With several angle tested within the range of 30º till 150º, the ultrasonic signal became smaller when it reached the bend angle area as in Figure 4, and this change of the ultrasonic velocity characteristic can be used to identify any defect on the pipeline.

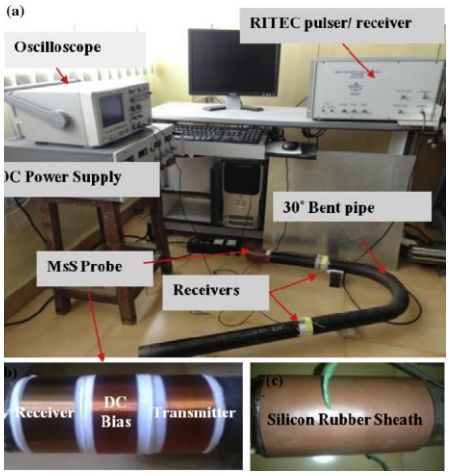

Figure 3 Photographs of the experimental set up, showing: (a) a view of the whole experimental apparatus; (b) coil arrangement in the MsS sensor used for the experimental study and (c) MsS Sensor [11]

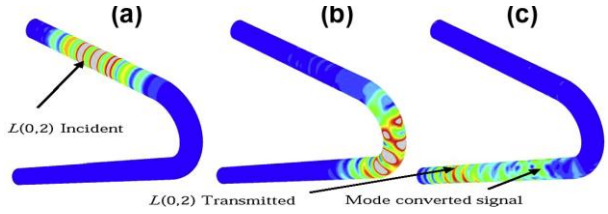

Figure 4 Snapshots of the contour of total displacement magnitude at different time (a) before, (b) at bend angle and (c) after bend angle by using Finite Element Simulation [11]

Turo *et al*. [12] applied the UT for manufacturing application to inspect the powder metallurgy part. Powder metallurgy is a process of producing mechanical part from metal powder and other components. The size and the location of fault and defect of powder metallurgy (Figure 5) can be detected by using UT system.

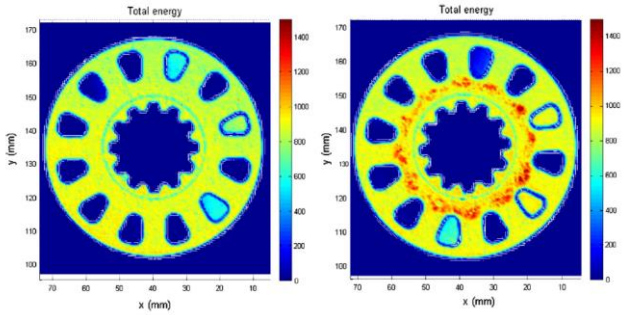

Figure 5 Complete C-scan of a defect free sample (left) and a defected sample (right) [12]

■3.0 INSPECTION SYSTEM BASED ON X-RAY TOMOGRAPHY

X-ray tomography was the first types of tomography introduced in medical applications during 1970s. However, later on it also widely used in process tomography. Works based on attenuation of x-ray, X-ray tomography promise a good tomogram with high resolution. X-ray tomography implemented in many applications. Here, the interest is only to report the use of X-ray tomography in inspection system. Similar with UT, X-ray Tomography also applied in civil application for inspection the cement material as proved by Han *et al.* [13]. In the order, they compare the condition of cement paste before and after drying. The cementing material also compared with mortar as in Figure 6. Sometimes, it is quite difficult to know any defect in cement paste. The condition of cement material can be known clearly by using X-ray Tomography. Also, the small pores of cement material can be detected. It can give high impact to the application that using the cement material such as a bridge.

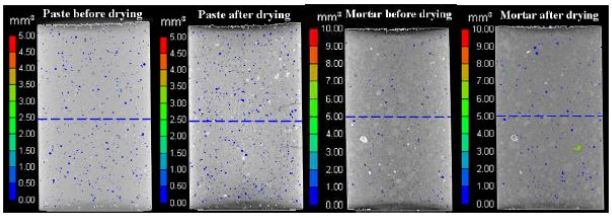

Figure 6 Tomogram of paste cement and mortar before and after drying [13]

Despite in civil application, X-ray tomography had been successfully implemented in the automotive industry for inspection purpose. Limodin *et al*. [14] for example used X-ray micro-tomography for inspection of aluminum alloys as shown in Figure 7. The pores and fracture of aluminum alloys can be easily detected by using the X-ray tomography.

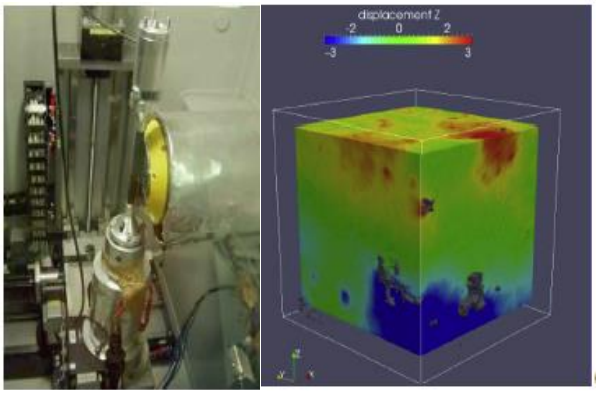

Figure 7 (a) Experiment setup for inspection system (b) 3D tomogram of aluminium alloys with pores [14]

Airkhanov *et al*. [15] employed X-ray tomography in investigating the condition of multi-material components, which contain metal parts surrounded by plastic materials; just as housings or connectors with metal inlays in the electronic or automotive industry. Figure 8 shows the model of the image reconstructed of the metal artifacts.

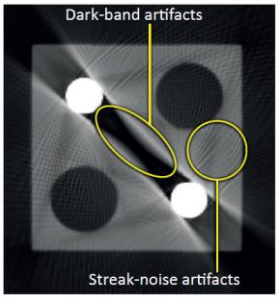

Figure 8 Example of metal artifacts [15]

A new research had been done by Lenko *et al*. in using X-ray Tomography comprehensively for inspection of high voltage application in the electrical industry. In this system, a defect in bar insulation was successfully visualized based on X-ray tomography method. The X-ray micro computed tomography can detect the accurate location and orientation of micro-scaled defects. Besides, inspection of ground wall of rotation machine had been made by Contin & Shena [16]. Here, the use of X-ray Tomography applied for detecting the internal features of two types of ground-wall insulation systems of ac rotating machines.

■4.0 INSPECTION SYSTEM BASED ON OPTICAL TOMOGRAPHY

Optical Tomography (OT) reconstructs the image based on the optical radiation; it transmits a beam of light from one boundary and receives the beam light from another boundary. If compare to X-ray tomography, the OT has its own advantage which is safe (not involve radioactive source) [17]. A large numbers of OT applied in medical application as X-ray tomography, but it also is a preferable measurement procedure for industrial applications. A review paper done by Change *et al*. [18] had given attention on the use of OT including possibility of OT for inspection system.

In this paper, the technology involving OT had been highlighted. In addition, OT looked can be implemented in manufacturing industry. Particularly, Cho *et al*. [19] evolved the technology of OT for inspection possible wire disconnection in LED manufacturing process industry as shown in Figure 9 and Figure 10.

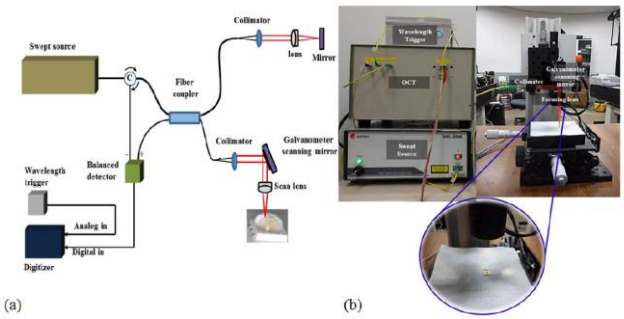

Figure 9 Swept Source Optical Coherence Tomography (SS-OCT) system; (a) Schematic diagram of SS-OCT, (b) Real SS-OCT system [19]

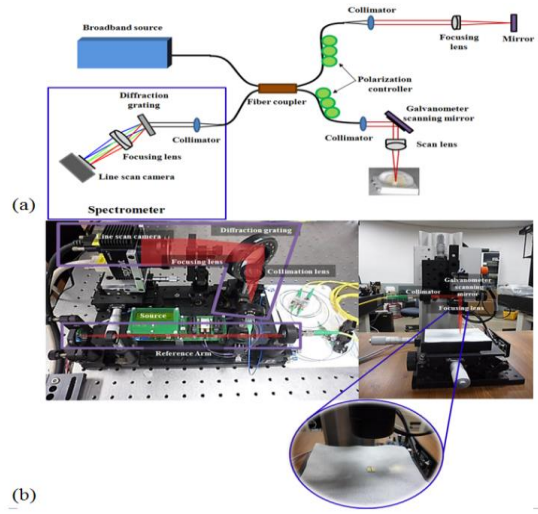

Figure 10 Spectral Domain Optical Coherence Tomography (SD-OCT) system; (a) Schematic diagram of SD-OCT, (b) Real SD-OCT system [19]

In this paper, two methods had been implemented which Swept Source Optical Coherence Tomography (SS-OCT) system and Spectral Domain Optical Coherence Tomography (SD-OCT) system. Both methods were reliable to implement for inspection of LED but with different wavelength (Figure 11). However, the best approach for wire inspection in LED was SD-OCT compared to SS-OCT.

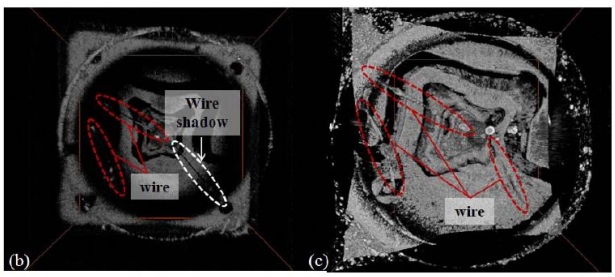

Figure 11 Tomography of circle chip LED from top view; (a) based on SD-OCT, (b) based on SS-OCT [19]

■5.0 INSPECTION SYSTEM BASED ON ELECTRICAL TOMOGRAPHY

Instead of hard field tomography stated in the previous sub topics, inspection system can be made by using soft field tomography; electrical tomography. There are many types of electrical tomography namely Electrical Capacitance Tomography (ECT), Electrodynamics Tomography (EChT), Electrical Resistance Tomography (ERT), and Electrical Impedance Tomography (EIT). At the moment, the ERT and EIT had been explored by researchers for inspection purpose. ERT, for example, reconstruct the image based on the resistance distribution materials. Due to its advantages such as non-intrusive, low cost and no radiation make ERT used for industrial application. Inspection of the concrete pillar that is a part of civil application by using ERT investigated by Peslaru *et al*. [20]. Focus on designing measuring apparatus successfully done for ERT. The measuring apparatus called ASMR that based on electronic circuit applied for inspection of concrete pillars as shown in Figure 12. The ERT was capable of having a good function to be used for inspection of concrete pillars.

Figure 12 ERT measurement apparatus called ASMR [20]

As well as ERT, EIT is reconstructs the image based on the conductivity distribution of material. In civil application specific for inspection system; EIT also performed to determine the moisture content in the brick wall [21]. The author came out with the EIT system that can provide 3D humidity in the brick wall. The technique can eventually lead to much easier, low cost and efficient in evaluating the moisture content in walls.

■6.0 CONCLUSIONS AND FUTURE POTENTIAL RESEARCH ON INSPECTION SYSTEM BASED ON PROCESS TOMOGRAPHY

Process tomography has expanded vigorously in inspection system. The works in last decades demonstrate clear application that utilizes the tomography for inspection system; mostly applied in civil application compared to other applications. Based on the main purpose of inspection, a different process tomography can be implemented successfully. Every type of process tomography has advantages and disadvantages. However, the similarity of tomography that is non-destructive method made it widely used in industry applications.

It is believed that, the future research on inspection system based on current research, especially in civil application can be expanded into inspection for sea underwater concrete pillars. It can be clearly seen that there is no research on the sea underwater concrete pillar that utilizes the process tomography made yet by researcher. This potential research could be done for better quality

of sea underwater pillar condition for long term period. It might be using the ultrasonic tomography or other types of process tomography since that this process will not disturb the natural medium/object interested. Moreover, a detailed study must be made to make sure that this tomography method can apply for sea underwater concrete pillars inspection.

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