Portable Gamma-ray Tomography Instrumentation for Investigating Corrosion under Insulation of Pipelines

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Abstract: - The objective of this research endeavor is to develop a Portable Gamma-ray Tomography Instrumentation for investigating corrosion under insulation of pipelines. Gamma ray densitometry is a non- destructive method for determining the density. The principle of gamma ray tomography measurement is based on the absorption of gamma radiation in the tested material. The scanning is performed using a small radioactive source and a sensitive electronic detector. The source and detector are kept external to the pipe and positioned on opposite sides at a fixed distance apart. Gamma rays travel from the source through the pipe to the detector where they are counted. The research covers the hardware design, implementation of measurement electronics as well as the software to receive the intensity counts, convert and display a tomographic image that corresponds correctly to the pipe condition of the pipe being scanned. The research concentrates on pipe condition and not the flow in the pipe. The collected data in the form of intensity is converted to a suitable signal and input in offline mode to produce a tomogram.

Keywords: Gamma ray transmission, tomography, instrumentation, corrosion under insulation

1 Introduction

Within industries that use industrial insulation, there are many integrity and safety challenges. One of the more serious issues, Corrosion under Insulation (CUI) is one that requires urgent attention. CUI is corrosion of pipes, tanks, and equipment which occurs under the pipe insulation and, in many cases, is caused by insulation. The root cause is simple: At the interface between the pipe insulation and the substrate to which the insulation is applied there is a temperature differential. Regardless of how tight a pipe insulation material is wrapped around, or applied to, the substrate there is a space where the temperature makes a quick change from higher to lower and that causes a release of moisture, commonly referred to as condensation, and that causes rust and corrosion. The mechanism of corrosion under insulation involves three requirements:

i. Availability of oxygen.
ii. High temperature.
iii. Concentration of dissolved species.

As the temperature increases, the amount of oxygen dissolved in solution decreases as the boiling point is reached resulting in reduced corrosion rates. However, on the surface covered by insulation, a poultice effect is created which holds in the moisture which essentially makes it a closed system. In fact the measured corrosion rates associated with corrosion under insulation follow trends to higher corrosion rates commonly associated with only pressurized systems. Furthermore, in cases where precipitation becomes trapped on the metal surface by insulation, corrosive atmospheric constituents such as chlorides and sulfuric acid can concentrate to also accelerate corrosion. In some cases, chlorides are present in the insulation which greatly promotes corrosion of the underlying surface which it becomes laden with moisture. There are three types of corrosion that can take place under insulation [2]:

1. Alkaline or acidic corrosion

2. Chloride corrosion

3. Galvanic corrosion

Corrosion under insulation (CUI) is exactly as it says, over time pipes may corrode while set inside the insulation, the pipes are shielded from the naked eye and so often go unnoticed. The pipes often carry high-pressure gas, oil, hydrocarbon and many other highly dangerous chemicals that are used in the processes of Petrochemicals manufacturing. The implication of corrosion on these critical pipes is insurmountable. Corrosion causes pipe deterioration, leading to damage resulting in leakages. These leakages often cause fires, massive explosions and fatalities. A huge resource drain in this arena in terms of money, man-hours and materials is known as Visual Search. Visual Search is used widespread in the industry and is the only guaranteed method of detecting corrosion, as the insulation is physically stripped, the pipe examined, replaced where necessary and the insulation then re-fitted. The visual strip and search method is generally carried out over a five-year period. This method is an industry headache and massive resource drain. On average, moisture or/and corrosion is often found in 5-20% of inspected pipe, thus 80-95% needn't be stripped in the first place as the integrity and condition of the pipe is often found to be sound. An appropriate pipe corrosion monitoring system would reduce the number of pipes being stripped unnecessarily and number of pipe failures and plant shut-downs. This is turn will have very positive economic effects.

A method, preferably non-destructive in nature, is required to precisely perform this measurement whose data will be used as a basis for determining whether or not the pipes need to be replaced. Theoretically, it is believed that radiographic method would be able to perform this function. It has the potential to be used to perform inspection without the need of costly removal of insulation material during operation of the plant. Furthermore, it offers an additional advantage of being capable to perform measurement in high temperature environments. It would be highly cost effective to use appropriate Non-Destructive-Testing (NDT) techniques to detect CUI without removing the insulation.

Gamma-ray tomography is intended for the inspection of CUI as it is a non-destructive and contact-less procedure, therefore, can be used for pipes at, essentially, any temperature. It is able to produce the image of the cross-sectional slices of the investigated pipe

2 Gamma-Tomography

Conventional gamma ray computed tomography methods measure the attenuation of an incident beam that travels in a straight path through an object. The incident beam is partially absorbed and scattered in the object of interest, with the remaining transmitted radiation traveling in a straight line to the detector. The amount of attenuation is related to the atomic number of the phases distributed in the object, as well as their density distribution8. As with radiography, access to both sides of the structure is required. [20]

The gamma tomography measurement system was originally developed for the investigation of fluid and gas distributions in rotating turbo machines. Engines, such as axial compressors, pumps, and hydrodynamic couplings usually have metal housings and components which are non-transparent and radiologically dense. Therefore, in most cases the object of interest is difficult to access by conventional flow measurement techniques. Gamma densitometry, radiography, and tomography are suitable and often the only applicable measurement techniques for such constructions.

3 Hardware Implementation

The hardware consists of a radioactive source, Barium-133 that emits gamma radiation with the activity of 3mCi. In order to detect the gamma photon we use scintillation detectors. A Thallium-activated Sodium Iodide [NaI(Tl)] detector crystal is used. This is due to this crystal's optimal detection efficiency for the gamma ray energies of radionuclide emission. Only a very small amount of light is given off from the scintillation detector. Therefore, photomultiplier tubes are attached to the back of the crystal. At the face of a photomultipler tube (PMT) is a photocathode which, when stimulated by light photons, ejects electrons. The PMT is an instrument that detects and amplifies the electrons that are produced by the photocathode. At the base of the photomultiplier tube is an anode which attracts the final large cluster of electrons and converts them into an electrical pulse. The source and detector are attached to a gantry and is moved along an x-axis and y-axis using a simple motorized contraption. The interval of movement source and detector is 2mm. One reading is taken every 2mm of movement along the *x* and *y* axis. The pipe measured is variable according to the industry.

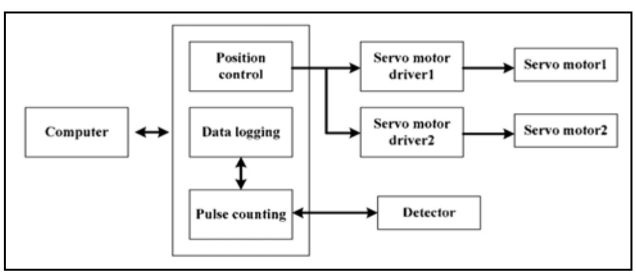

Figure 1: Block diagram of hardware designed

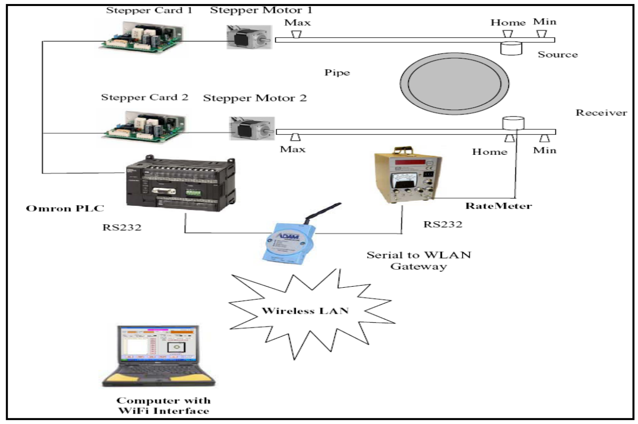

Figure 2: Structure of hardware

3 Reconstruction Algorithm

Several tomographic reconstruction methods are described in the literature [6], [7], [8], [9] and the method of choice depends on the quality of projection data. Although filtered back projection (FBP) gained popularity as a very fast reconstruction technique there are limitations in the image quality produced. To a large extent this is due to the back projection process and the necessary filtering. An alternative to FBP is to use iterative reconstruction. [21]. Although there are many iterative reconstruction techniques, the technique in use is the maximum likelihood (ML) reconstruction, which is the most commonly used approach. ML reconstruction usually is performed using the expectation maximization (EM) algorithm [22, 23]. The algorithm is said to converge to a solution when the change between successive iterations is minimal. Note that the forward projection step can be thought of as the inverse of back projection. However, unlike FBP, no filtering was necessary to reach a solution, although a smoothing filter is frequently used to control noise. The major advantage of iterative reconstruction techniques is that they permit the emission and detection process to be accurately modelled. In contrast, the filtered back projection algorithm makes no allowance for the physics of emission including attenuation and scatter of the emitted photons. The model can be quite comprehensive, to include the variation of resolution with source-detector position and the incorporation of measured variable attenuation. [21]

4 Conclusion

The portable instrumentation described gives many technical and economic benefits to industries with a need to inspect corrosion under insulation of pipelines and it is an excellent alternative to the methods currently in use as it is a non-destructive and contact-less procedure.

References:

[1] Baldev Raj, T. Jayakumar, M. Thavasimuthu. “Practical Non-destructive Testing.” Woodhead Publishing, 2002.

[2] Philip A. Schweitzer. “Encyclopedia of Corrosion Technology.” CRC Press, (2004)

[3] Linda Garverick. “Corrosion in the Petrochemical Industry.” ASM International, (1994)

[4] U. Zscherpel, Y. Onel, U. Ewert. “New concepts for corrosion Inspection of Pipelines by Digital Industrial Radiology (DIR).” 15th World Conference on Nondestructive Testing Roma (Italy), October 2000.

[5] U. Zscherpel, Y. Onel, P. Willems. “Radiographic Wall Thickness Measurement of Pipes by a New Tomographic Algorithm.” 15th World Conference on Nondestructive Testing Roma (Italy), October 2000.

[6] Michael Twomey, “Inspection Techniques For Detecting Corrosion Under Insulation.” Inspectioneering Journal Nov/Dec 1996.

[7] Chan Kok San. “Offline Image Reconstruction For optical Tomography.” Universiti Teknologi Malaysia : B.Sc Thesis. (2001)

[8] J.Abdullah, G.H.P. Mohamad, M.A.Hamzah, M.S.M. Yusof, M.F.A. Rahman & F. Ismail. “Portable computed tomographic system for in-situ inspection of industrial pipelines.”

[9] Gerhard Busse, Danny Van Hemelrijck, Igor Solodov, Athanasios Anastasopoulos. “Emerging Technologies in NDT.” Proceedings of the 4th International Conference of Emerging Technologies in Non-destructive Testing (Etndt 4), Stuttgart, Germany, April 2007, CRC Press, (2008)

[10] Kohl, R. and Dougan, K. “Methodology for detecting corrosion under insulation.”

[11] Hira S. Ahluwalia. “CUI: An In-Depth Analysis.” ASM Handbook Volume 13C, (2006)

[12] API 570, Inspection, Repair, Alteration, and Re-rating of In-service Piping Systems, Washington, D.C., API

[13] Herman, G.T.: Image Reconstruction from Projections: The Fundamentals of Computerized Tomography. Academic Press, New York (1980)

[14] Roerdink, J.B.T.M.: Computerized tomography and its applications: a guided tour. Nieuw Archief voorWiskunde 10(3) (1992) 277–308

[15] Vidya Elangovan and Ross T. Whitaker, “From Sinograms to Surfaces: A Direct Approach to the Segmentation of Tomographic Data”, Int. Conf. on Med. Image Computing and Computer-Assisted Int. (2001)

[16] Frank Natterer, “Algorithms in Tomography”.

[17] Rafael C. Gonzalez and Richard E. Woods, “Digital Image Processing”, Addison-Wesley, New York, (1992)

[18] Samir Abdul-Majid and Zuhair Tayyeb, “Use of Gamma Ray Back Scattering Method for Inspection of Corrosion under Insulation”, 3rd MENDT - Middle East Nondestructive Testing Conference & Exhibition (2005)

[19] Haijing Niu, Ping Guo, Lijun Ji, Qing Zhao, and Tianzi Jiang, "Improving image quality of diffuse optical tomography with a projection-error-based adaptive regularization method," Opt. Express 16, 12423-12434 (2008)

[20] Martz, H E, Schneberk, D J, Roberson, G P and Monteiro, P J, .Computerized tomography analysis of reinforced concrete., ACT Materials Journal, May/June 1993, pp 259-264

[21] Hutton, Brian F. An Introduction to Iterative Reconstruction. Alasbimn Journal 5(18): October 2002. Article N° AJ18-6.

[22] Lange K, Carson R. EM reconstruction algorithms for emission and transmission tomography. J Comp Assis Tomog 1984; 8: 306-316.

[23] Shepp LA, Vardi Y. Maximum likelihood reconstruction for emission tomography. IEEE Trans Med Imaging 1982; 1: 113-122.

[24] M. Rabbani and P.W. Jones, Digital Image Compression Techniques, Vol TT7, SPIE Optical Engineering Press, Bellvue, Washington (1991).

[25] Jaafar Abdullah, Rasif Mohd Zain and Roslan Yahya (2003). Pipe-CUI-Profiler: A Portable Nucleonic System for Detecting Corrosion Under Insulation (CUI) of Steel Pipes,In Proceeding of the 5th National Seminar on Non-Destructive Testing (NDT), pages 209-213, Shah Alam, October 2003.