NON-INVASIVE STRUCTURAL HEALTH MONITORING OF STORAGE TANK FLOORS

V. DIMLAYE[1], **P. MUDGE**[1], **P. JACKSON**[2], **TAT-HEAN GAN**[1] and **SLIM SOUA**[1]
[1]NDT and Asset Reliability Technology Group, TWI Ltd, Cambridge, CB21 6AL, Great Britain
[2]Plant Integrity Ltd, Cambridge, CB21 6GP, Great Britain. E-mail: tat-hean.gan@twi.co.uk

Large above ground storage tanks filled with hydrocarbon and hazardous liquids such as oil, oil-derived products, chemicals and process plant liquids are in widespread use in the UK, Europe and throughout the world. Tank farms are normally located in coastal areas close to large centres of population. Leakage from corroded storage tanks, especially from their floors, is a major environmental and economic hazard and poses a significant threat to those living in the vicinity of tank farms, as well as to the rest of the UK and Europe. The current, and growing, risk of tank failure together with the potential risk for fire and explosion at nearby petrochemical plants is wholly unacceptable. This paper illustrates the work carried out in the UK Technology Strategy Board (TSB) Tank Integrity Monitoring (TIM) project, for the structural health monitoring of large above ground bulk liquid storage tank floors without the need to access the inside of the tank or to empty its contents, using ultrasonic guided waves (UGW) as a non-destructive testing technique. A structural health monitoring system for acquiring ultrasonic guided wave data over long periods of time was developed. The performance of the permanent attached transducers and the structural health monitoring system was also investigated to demonstrate their reliability. The propagation of the guided wave signals has been validated experimentally on a 4 m diameter tank floor, and tomography imaging has been developed for detection and location of defects. 3 Ref., 6 Figures.

Keywords: *guided wave, ultrasonic, tank floor, tomography, storage tanks, structural health monitoring system*

Various NDT methods such as penetrant testing, magnetic particle, radiographic testing, eddy current, thermography and acoustic emission were used to inspect storage tank floors [1, 2]. Current inspection methods require the tank to be drained in order to create a safe environment, suitable for personnel entry, in order to carry out inspections which can be time consuming and expensive. As such, there is a need to develop a faster, lower cost and safer method to assess the structural integrity of tank floors. The objective of this study was to develop a structural health monitoring method for the tank floors using low frequency UGW. The low frequency UGW have the ability to propagate long distances in planar and tubular structures and is already used for the inspection of pipes [3].

Experimental set-up. *Tank monitoring system.* A 4 m diameter tank floor was used to carry out the structural health monitoring experiments for damage locality and detection. The wall thickness of the tank floor was 7 mm with a seam weld running along the diameter of the tank floor. The tank is shown in Figure 1.

Figure 1. Tank floor of 4 m diameter

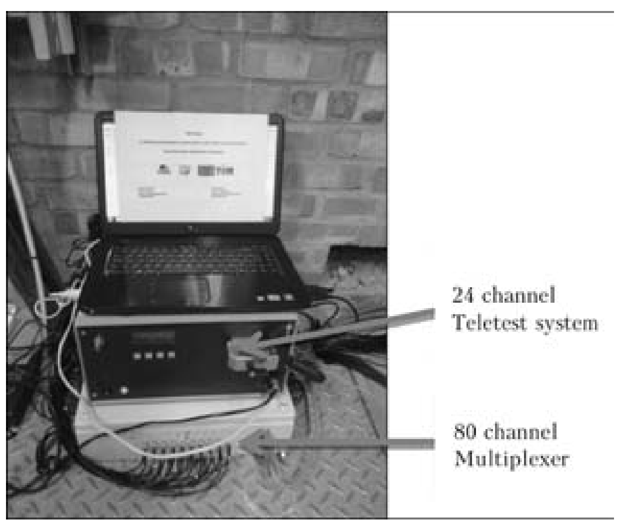

Figure 2. Tank floor structural health monitoring system

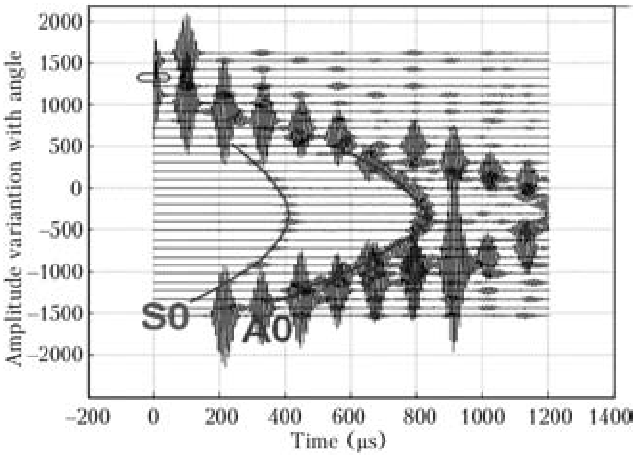

Figure 3. Time domain signals acquired

A multitude of transducers were permanently attached around the perimeter of the tank floor. The commercially available 24 channel Teletest system and an additional 80 channel multiplexer were used to collect a broadband frequency range of data. The botany of the tank floor structural health monitoring system is illustrated in Figure 2.

Ultrasonic guided waves. The ultrasonic guided waves propagating within the plate structure contain various wave modes; depending on the frequency of excitation, the fundamental wave modes generated are the symmetric S0 and asymmetric A0 wave modes. In this study, the characteristics of the S0 wave mode are used. The presence of the S0 and A0 in the acquired time domain signals is illustrated in Figure 3.

Result. *Reliability*. The structural health monitoring system was used to collect data continuously over three months. One very important factor for a robust structural health monitoring system is the reliability of the transducers and electronics. The stability of the aforementioned transducers, which were studied over the three month time period, are illustrated in Figure 4, the results of which can be displayed using tomograms that were intermittently generated. It can be seen that the distribution of the energy over the circular structure is fairly constant over a prolonged period of time suggesting no failure or degradation in the performance of the transducers and electronics.

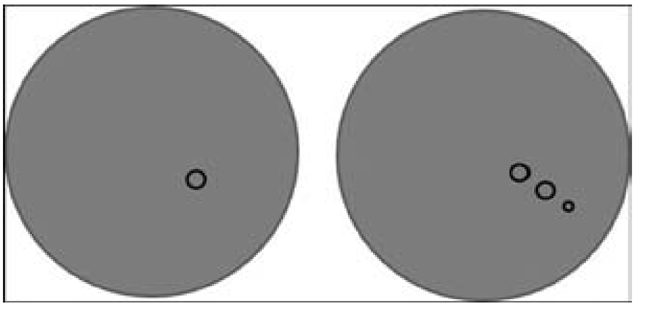

Figure 5. Defect size and location: 70 mm defect (*left*) and 70, 70 and 20 mm defect (*right*)

Defect detection and location. The capability of defect defection in terms of size and location was studied. A large set of baseline data were acquired which covers wide environmental condition changes. A single defect of diameter 70 mm and through thickness were introduced initially, then a second and third defect of 70 and 20 mm, respectively, were then added to the tank floor. A set of data was then collected after each defect addition. The positions of the defects are shown in Figure 5.

The tomograms were generated using characteristics of the S0 wave mode acquired at the

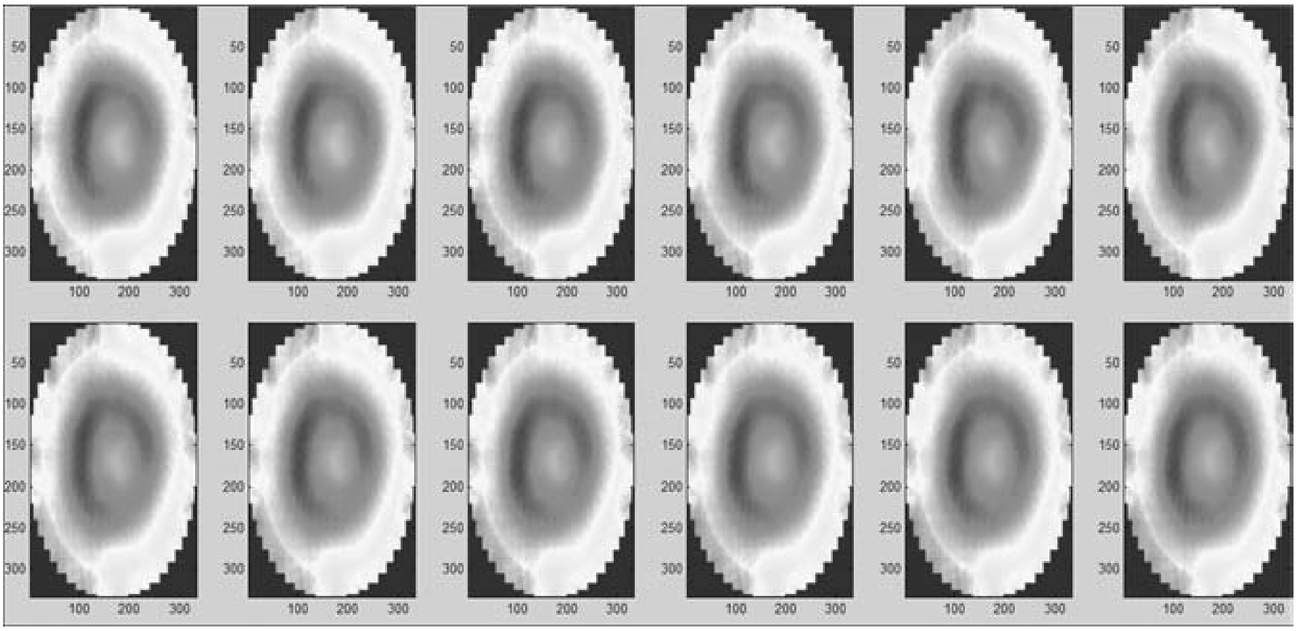

Figure 4. Tomography representation for the stability of transducers

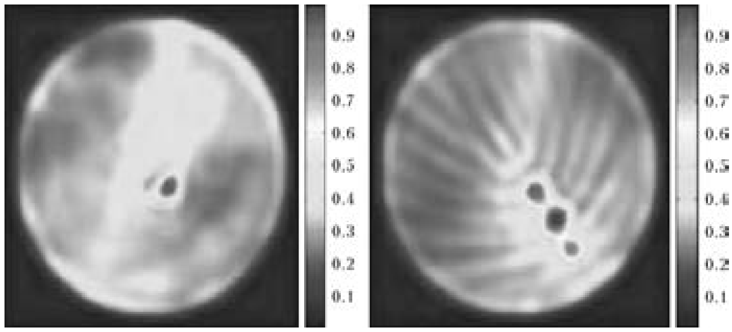

Figure 6. Tomograms for 70 mm defect (*left*) and for 70, 70 and 20 mm defects (*right*)

opposite receiving transducers. The detection and location of the added defects have been made possible by the tomography technique used. The tomograms are shown in Figure 6.

Conclusion

The use of ultrasonic guided waves for the structural health monitoring of storage tanks has been investigated on a 4 m diameter tank floor. For the purpose of structural health monitoring, it is of paramount importance to have a reliable system in terms of transducer performance and a stable pulser-receiver system. The experiments carried out, based on the data acquired, demonstrate the stable performance of the permanently attached transducer and of the pulser-receiver used. The S0 wave mode from the receiving transducers has been used to generate the tomograms. The tomography technique has been successfully implemented alongside the developed structural health monitoring system for the detection and location of defects of 20 to 70 mm in size.

Acknowledgements. *The work was sponsored by the Technology Strategy Board (TSB) under the Tank Integrity Monitoring (TIM; www.tim-project.co.uk) project. The project was managed by TWI Ltd (UK). The author would like to express thanks for the support from the TIM project partners namely Shell, Vopak and NuStar Energy.*

1. Cawley, P., Lowe, M.J.S. et al. (2003) Practical long range guided wave testing application to pipe and rail. *Material Evaluation*., 61(**1**), 66–74.
2. Pei, J., Yousuf, M.I., Degertekin, F.L. et al. (1996) Lamb wave tomography and its application in pipe erosion/corrosion monitoring. *Research in Nondestructive Evaluation*. 8(**4**), 189–197
3. Sicard, R., Goyette, J., Zellouf, D. (2002) A SAFT algorithm for lamb wave imaging of isotropic plate-like structures. *Ultrasonics*, Vol. 39, 487–494.

Received 06.06.2013