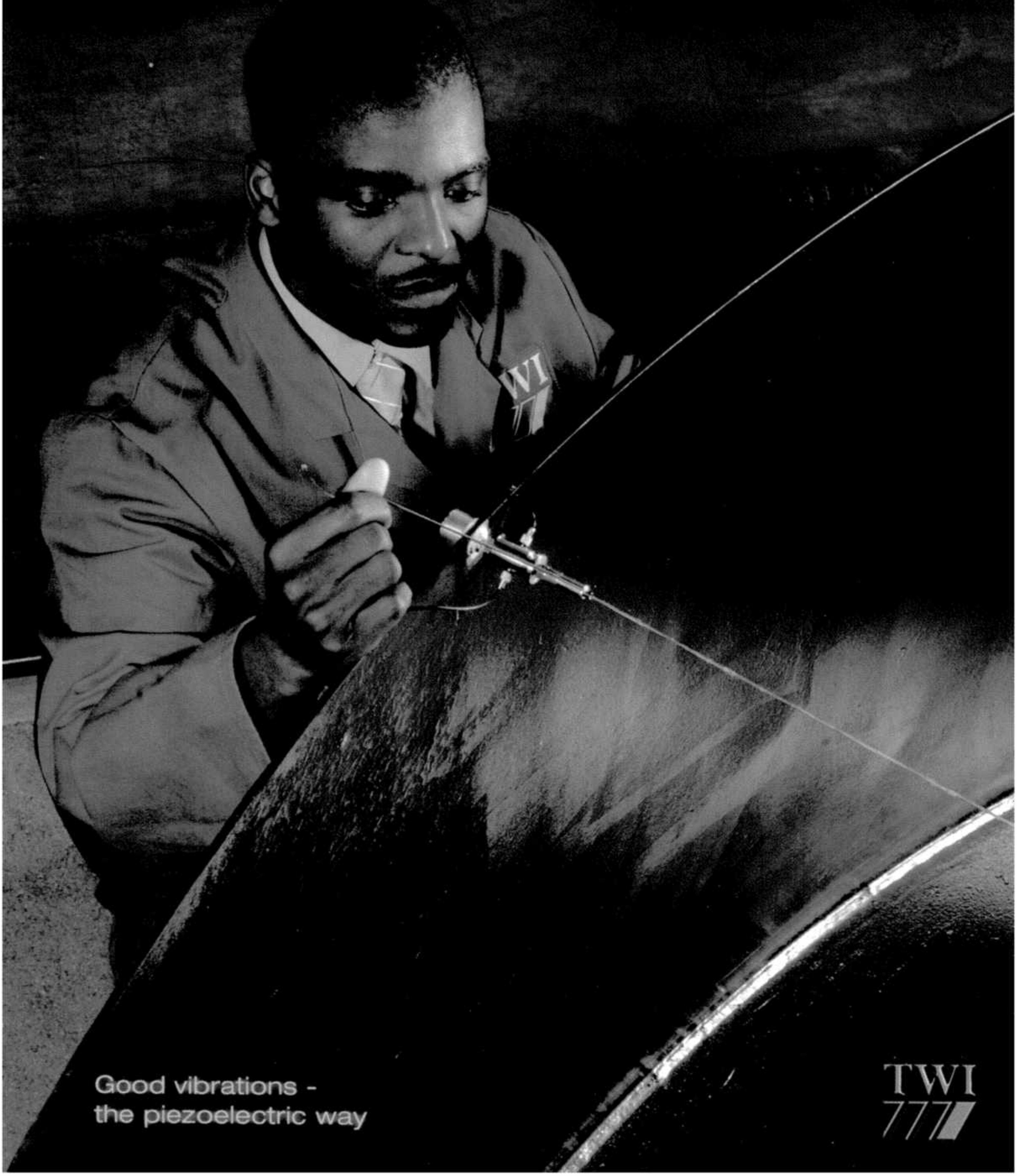
THE bulletin

sep/oct 2005

the technical journal for industrial members of twi



Good vibrations -
the piezoelectric way

TWI

Detecting microscopic structural vibrations for monitoring storage tanks - with piezoelectric transducers

NDT plays an important part in the maintenance of any large engineering structure and the provision of 100% coverage in a practicable time-scale remains a challenge to development engineers.

Stephen Williams reports on a laboratory experiment that explores the possibility of using piezoelectric transducers to both generate and measure the modal properties of a model storage tank wall, thereby offering the potential for condition monitoring of real tanks and other large engineering structures.

Stephen Williams joined TWI in 2001 and works in the area of non-destructive testing as a senior project leader. He has been involved in various projects developing new testing techniques. Before joining TWI he did a PhD at Bristol University developing a tap test method for condition monitoring of structural steelwork. He also worked for three years at the Gillette R&D laboratories in Reading.

This project was dedicated to the development of a novel concept. The project consortium has named it 'PD' (piezodiagnostic) technology. The principle is that by testing at frequencies that excite global structural vibrations, scattering can be reduced leading to much longer testing ranges than achievable with Lamb waves. The novelty of the piezodiagnostic approach was to excite with piezoelectric rather than electromechanical devices, thereby generating microscopic vibrations. Such low amplitude vibrations require much less energy to induce in the structure. They are intrinsically safe and represent a practical approach to structural dynamic testing when condition monitoring large structures.

This article seeks to determine whether, by using microscopic structural vibrations, PD technology offers a practical solution that can be implemented on storage tank walls. Furthermore it seeks to determine whether the sensitivity obtained by using such vibrations for modal testing is sufficient to allow the detection of structural change comparable with typical corrosion losses.

The industrial significance of developing a method capable of condition monitoring a whole tank wall is considerable. Real tank walls have vast surface areas, which are impractical to scan by manual or semi-automatic methods such as robot crawlers. The failure of a stiffener may not even be visible without close inspection. Other potentially hazardous changes are brought about by corrosion and erosion caused respectively by moisture accumulation and by moveable roofs (see TWI member report 800/2004 on 'JoinIT'). The ability to be able to identify such changes with minimal disruption to the service of the tank would be a great advantage.

Objectives

- To investigate by experimentation the possibility of obtaining modal properties from the wall of a model storage tank by generating and detecting microscopic structural vibrations with piezoelectric transducers (PD technology).

- To assess the potential of PD technology for detecting structural modifications typical of localised corrosion in storage tanks.

For long-range testing of large structures, two elastic wave approaches were considered in the present research namely, Lamb waves (often used at frequencies between 30kHz and 200kHz) and dynamic structural vibrations (frequencies around the lower order modes). However, despite the numerous potential industrial applications for

Lamb wave inspection of flat plate-like structures, there are no commercial systems to date. The main obstacle would appear to be the rapid loss of signal strength with increasing distance from the transducer due to beam spread and scattering at structural features such as welds.

At the lower frequencies of structural dynamic vibration, the wavelengths are long compared with the size of structural features minimising the effect of scattering. At natural frequencies these are effectively standing waves so there is no longer a problem of energy loss through beam spread. Dynamic testing is the oldest form of NDT, perhaps beginning in ancient times with the tap-testing of pottery. More recently, the railway wheeltappers' test was used to detect cracks in train wheels. The potential scope of dynamic testing has since broadened, owing to the availability of electronic instruments capable of fast Fourier transforms (FFTs).

Experimental approach

The main approach was to obtain the modal response of the tank wall by conducting a stepped frequency scan and comparing the fingerprint generated under different configurations (locations of transducers) and in different tank states (location of added mass). In a stepped frequency scan the excitation frequency is changed in steps of a fixed size. At each frequency, a steady state sinusoidal structural response is established and measured simultaneously at a number of locations on the structure. At a mode the structural vibrations reinforce (constructive interference) and a large response is measured. The frequency response function (FRF) was used for fingerprint analysis. It is defined as:

FRF = Response / Force

Equipment and apparatus

Transducers

The force was measured by a sensor located in an impedance head. The response was measured by five sensors; one of these sensors was a Bruel and Kjaer type 8001 impedance head. The other four sensors were prototype devices provided by the project partner CEGELEC CNDT of France. The response of these sensors was proportional to local deformation. A conventional FRF is derived from displacements, velocities or accelerations and therefore these sensors do not directly measure the FRF. However, it is reasonable to assume that some consistent relationship exists between radial displacement and local distortion in the region of the sensor.

The sensors, together with the impedance head, each generated an independent transfer-FRF (in a transfer FRF, the force and response are measured at different locations). The basic structure of the CEGELEC sensor is shown in Fig.1a. It is attached with a layer of fast-acting HBM X60 epoxy (a very hard adhesive). The actuators supplied by CEDRAT of France are amplified piezo-actuators (APA). The basic structure is shown in Fig.1b. The actuator works by pulling its two poles together in response to an applied voltage within the range -20V to 150V, generated by the conditioning unit from an order signal between -1.0V and 7.5V. The voltage causes the bar of piezo-ceramic material between the poles to extend and contract axially.

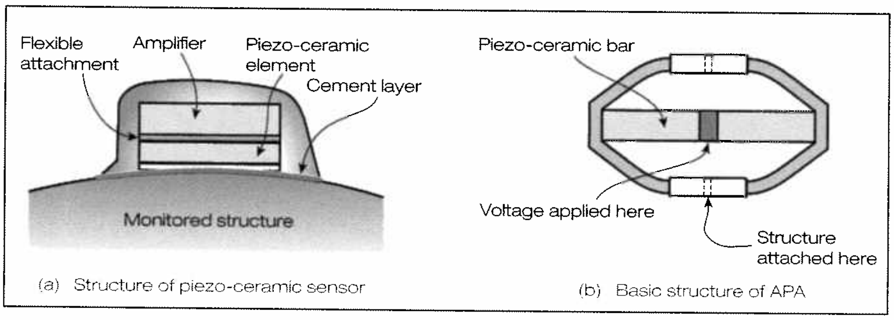


Fig. 1. Piezoelectric transducers for PD experiments on model tank

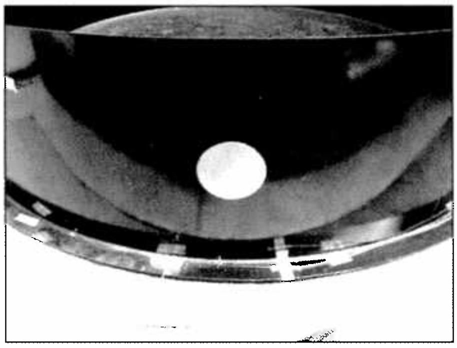
Model tank and added mass

The model tank was designed and built at TWI. It was a 4m diameter tank with a bottom plate comprising two 6mm thick semi-circular plates of steel. The plates were butt-welded together and a one metre high shell consisting of three sections was welded to the bottom plate with full penetration fillet welds. The three sections were themselves butt-welded together. The bottom plate was trimmed to leave a rim of 100mm. The tank was mounted on sand to represent the foundation material.

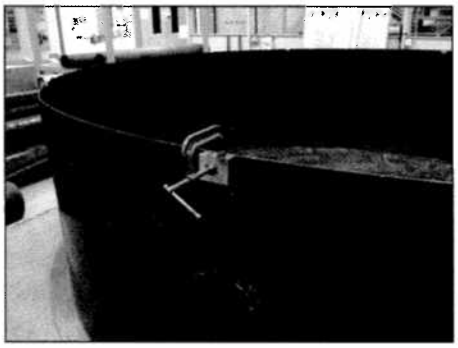
In this experiment added mass rather than metal loss represented structural change due to corrosion. Loss of section due to corrosion primarily reduces the local mass and stiffness causing changes in the FRF. An equivalent increase in mass is expected to cause local stiffness increase and comparable changes in the FRF. Added mass is also more convenient as it is reversible. There were two attached masses and these are illustrated in Fig.2a and Fig. 2b. One was a 1kg circular steel disc of 2.5mm (half wall) thickness and 26cm diameter. This was attached to the wall with Araldite rapid adhesive. The other was a 0.90kg steel block attached with a G-cramp.

Testing apparatus and configurations

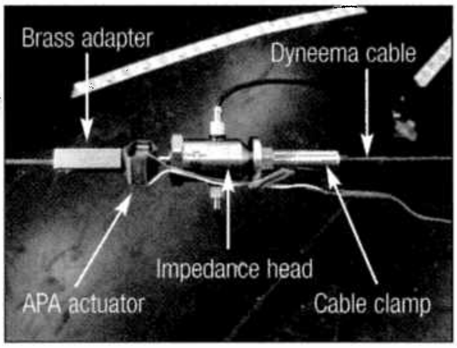
The tank wall was excited with the 'active-tendon' configuration. Each end of the actuator is connected to an adapter that interfaces it with a Dyneema cable (made by Eurocord BV). This material was chosen mainly because it was



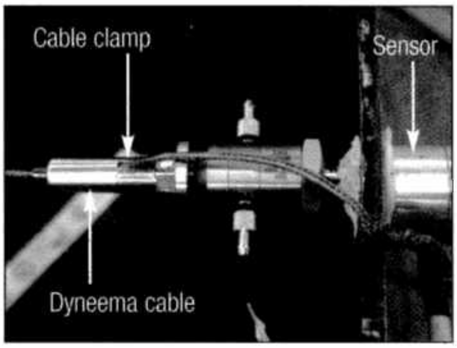
(a) With plate (1kG) attached



(b) With block (0.896kG) attached



(c) 'Active-tendon' (tank centre)



(d) 'Active-tendon' (tank wall)

Fig. 2: Tank monitoring apparatus

Table 1. Summary of tank wall experiments with actuator connected between location 243.

Experiment No	Tank state	Scan resolution (Hz)
1	Unmodified	0.1
2	W(a)	0.1
3	W(b)	0.1
4	W(d)	0.1
5	Unmodified	0.1
6	Unmodified	1
7	W(d')	1

lightweight and therefore the effects of self-weight would be negligible. The cable is attached to the tank wall with a clamp and a light tension (~100N) was applied. Fig. 2c shows the actuator suspended in the centre of the tank and Fig.2d shows the actuator's wall mounting. The two positions of the impedance heads allowed verification that the force produced by the actuator was undistorted by the cable. Fig. 3 illustrates the different testing configurations and tank states. In this figure the numbers indicate transducer locations.

Experimental procedure

To test the PD concept on tank walls, stepped frequency scans were conducted using piezoelectric actuators and sensors. The experiments are summarised in Table 1. In the first five of the experiments scans were performed between 1Hz and 200Hz at a frequency resolution of 0.1Hz. In these experiments the tank was either unmodified or modified with the added mass. Two follow-up stepped frequency scans were performed in the range 85Hz to 115Hz with a step size of 1Hz: five repeat experiments with the tank in the unmodified state (experiment six); and eight repeat experiments with the smaller mass clamped at d' (experiment seven, Fig.2 and 3).

Summary

The experimental set-up described in this report allows the testing of a fundamentally new approach to the condition monitoring of storage tank walls and, by extension, large structures in general, namely modal testing with low amplitude vibrations.

The work described in this report was conducted at TWI and jointly funded by the TWI core research programme (CRP), and partly by the EC through a 5th framework project called 'Piezodiagnostics'. The project consortium had nine partner companies from the UK, France, Poland and Spain. Piezodiagnostics was part of the EC GROWTH programme, its duration was three years and it took place between 2002 and 2005 (visit http://www.cordis.lu/ for details).

This is the first part of a two-stage report. Part 2 gives the experimental results.

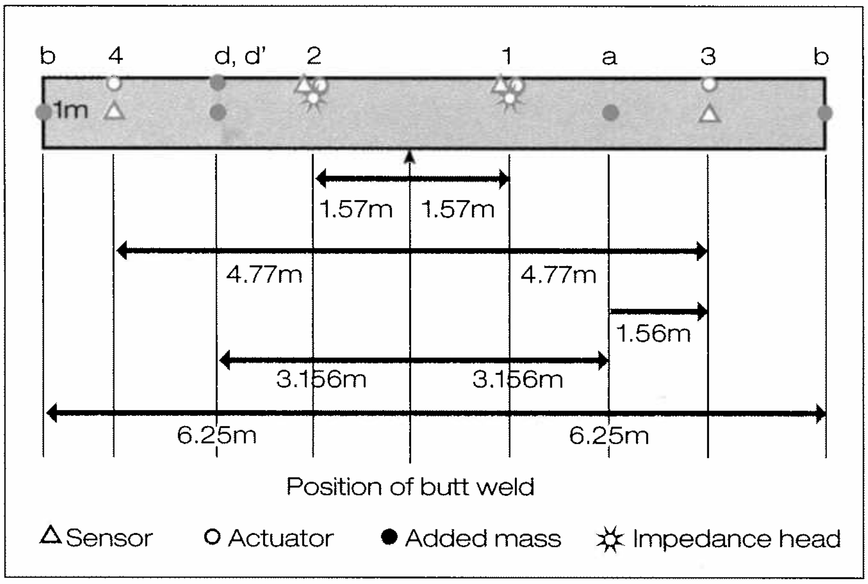


Fig. 3. Tank states and testing configurations