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CONTINUOUS CONDUCTING GUIDED WAVE ENCODED SENSOR FOR FLOOD SEARCHING OF OIL RIGS CROSS BEAMS

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Abstract

Structural flooded member searching of offshore oil platforms involves the searching of seawater in their normally hollow steel crossbeam members. NDT methods such as ultrasound have been used to inspect for the presence of water in these applications, often in conjunction with remote operating vehicles. Alternatively, a guided wave sensor system is now being developed which can be permanently attached to a sub-sea installation and that can be powered by the action of the seawater. Upon activation the transducer is able to transmit encoded information to conducting systems at deck level. Present work has focused on the assessment of guided waves and their attenuation not only due to steel joints and distance but also due to leaky waves coupled into surrounded water. Low frequency excitation exhibits lower attenuation depending on the selected mode, however also can be exposed to acoustic interference leading to a poor SNR. A compromise between these factors has been considered in this application for the successful transmission and reception of encoded information.

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Low power narrow bandwidth chirp signals were employed with 21 kHz PZT transducers to excite axi-symmetric modes in tubes. Experiments have been carried out using excitations of 0.5V and 5V respectively for water loaded steel k-joints scale model of 4mX0.18mX0.007m and a cylindrical bridge steel structure of 53m long and several k-joints of 0.5m and 0.4m diameters. Important results have been attained, moreover in order to reduce acoustic noise a real time digital signal processing board has been used to perform digital filtering and signal identification.

Introduction:

Crossbeam members used in offshore steel structures are normally made from sealed steel tubes filled with air. The infiltration of water in these beams is a serious issue, leading to impaired structural performance and the onset of corrosion. This critical matter is used as a basis for an inspection method known as Flooded Member Searching (FMD). Reinforcing members are regularly inspected for flooding using NDT underwater ultrasonic probes. These systems are, however, expense to hire and operate, requiring the deployment of a diver or a remotely operated vehicle. As an option the development of an ultrasonic sensor, for the purpose of Flooded Member Searching is in progress. The system, which will employ audio-range or ultrasonic transmission transducers, will be attached to the inner wall of the lower attachment point of a given crossbeam and will be powered by the action of the seawater. Upon activation, the transducer will transmit encoded information to conducting systems at deck level for decoding and identification of the sensor member, exploiting the guide-wave effect via low power PZT probes, allowing for the steel jacket structure as communication channel.

This work presents preliminary results obtained on the evaluation of guided waves and their attenuation not only due to steel joints and distance but also due to leaky waves pertain to guided

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waves in single elastic, isotropic layer immersed in surrounded liquid. Literature shows attenuation models for pipes and steel plates immersed in water. In immersed plates, the lowest-order symmetric modes are generated at low frequencies. Physically these modes are analogous to the lowest-order axi-symmetric mode in cylinders and rods. Low frequency excitation presents lower attenuation depending on the selected mode, however also can be exposed to acoustic interference leading to a poor SNR. A compromise between these factors has been considered in this application for the successful transmission and reception of encoded information.

Laboratory and field experiments have been carried out using low power narrow bandwidth chirp signals with 21 kHz PZT transducers to excite axi-symmetric modes in tubes, particularly the L(0,1) equivalent to A_0 [1]. Trials were performed via excitations of 0.5V and 5V respectively for water loaded steel k-joints scale model of 4mX0.18mX0.007m and a cylindrical bridge steel structure of 53m long and several k-joints of 0.5m and 0.34m diameters.

Important results were obtained both in the laboratory and in the field, however in order to reduce acoustic noise and improve SNR a real time digital signal processing board has been used to perform digital filtering and signal identification. Moreover, digital signal processing cross correlation was performed off line in lab tests which allowed the transmission of 5mV signals and the identification of signals embedded in noise.

Mode and transducer selection:

There are in theory an infinite number of guided wave modes in a cylindrical waveguide. The description of guided wave modes in pipes is based on two indices M and n. The former indicates the order of harmonic variation of displacement and stresses around the circumference and the latter the mode number. The types of modes described are: longitudinal, torsional and flexural. All of them propagate in the axial direction of a cylindrical waveguide. The acoustic

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fields of the modes when M = 0 are axis-symmetric along a cylinder circumference. Other the modes are non-axis symmetric. The axis symmetric modes are both longitudinal modes, L(0, n), and torsional modes, T(0, n) and the non-axis symmetric modes are represented by the flexural modes, F(M, n). Longitudinal modes are frequently preferred and more implemented in practical applications than torsional modes not only because of experimental aspects such as excitability and repeatability of the modes, but also because of the symmetry that allows the inspection of 360° along the circumference of the tubes. It has been demonstrated that a subset of dispersive curve modes in pipes is reducible to Lamb waves in plates in the limit of small cylinder curvature (large radius). The equivalent resonant modes are L(0,m) where $L(0,1) \cong A_0$ and $L(0,2) \cong S_0$ [1] For this reason standard Lamb wave data to determine the expected group velocities of these modes could be used. Classification of the velocity dispersion curves is attained, pragmatically, in terms of a frequency times the thickness, f_d of the waveguide, as it is described for plates. It is possible to have numerous guided wave modes with a single frequency and all of them with different velocities. The total number of guided wave modes for a given f_d value is finite and increases with an increase in frequency, nonetheless only the lowest order modes such as A_0 and S_0, can propagate at any frequency. Therefore, having a constant thickness, the selection of a low f_d value where the number of guide wave modes is reduced, depends of a low frequency which posses large wavelength.

An important attribute to consider due to a large wavelength is the overall size of the transducer, which must also be plausibly large in order to obtain some degree of directionality. The transducer size controls either the effective wavelength bandwidth with EMAT systems or the effective phase velocity bandwidth with piezoelectric excitation, while the excitation signal controls the frequency bandwidth. Generally, satisfactory mode control requires the transducer to be around 3-5 wavelengths long. S_0 mode has higher phase velocity than A_0 mode. For a S_0 mode with a phase velocity of 5 mm μs^{-1} the wavelength is 10 mm at a frequency of 500 kHz therefore a moderate transducer size is required. Nonetheless, for a frequency of 50 kHz the wavelength increases to 100 mm and the required transducer size becomes impractical. However, guided waves used in long range applications require the employ of frequencies below 100 kHz [2]. As an option, some authors have devised transducer arrays of point sources [3, 4]. However, for practical reasons of this application such as power excitation the use of a single monolithic transducer attached to the lower inner part of the crossbeam was envisaged. Hence it has been decided to use the A_0 mode which posses much lower phase velocity along with a single piezoelectric transducer.

The second characteristic governing the selection of a suitable mode is the level of guided wave attenuation due to leakage into the surrounding media. This is the case in this application where the surrounding media is seawater. Consequently it is desirable to use a mode which exhibits low leakage attenuation into surrounding liquids. Guided waves propagation of distances of over 25 metres in pipe diameters from 2 to 24 inch using rings of piezoelectric array and S0 mode have been reported [5]. These types of applications are focused in inspections looking for corrosion and defects, where sensitivity decrease as frequency is reduced. The L(0,2) mode has small but non-zero radial displacement, and so it loses energy slowly into a fluid surrounding the pipe. Literature shows attenuation models for pipes and steel plates immersed in water, attenuation rates caused by immersion in water are very low for L(0,2) normally at low frequencies but also depending on thickness and diameter of the specimen [6].]. However as the frequency increases the mode adopt lateral motion and the attenuation increase dramatically.

On the other hand, the A_0 mode has an important lateral motion over its entire frequency range therefore it is expected that always transmit energy into the surrounding liquid. This has precluded the use of the A_0 mode in some applications; however, L(0,1) mode does not behave in the same manner at low frequencies. As the A_0 phase velocity drops below the bulk velocity of the surrounding liquid the attenuation tends to zero [7]. Using the A_0 mode via 40 kHz PZT transducers in a steel tube of 500X130X5mm the authors have reported a phase velocity of 1.105 mm μs^{-1} and an attenuation of 4dB due to water loading [8]. Similar figures were encountered at

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low frequencies in attenuation models carried out in a water loaded copper tube by Aristegui et al [9]. Lessening the frequency A_0 mode excitation will exhibits lower attenuation levels however also can be exposed to acoustic interference leading to a poor SNR. A compromise between these factors has been considered in this application for the successful transmission and reception of encoded information, thereby single 21 kHz PZT transducers were selected.

Experimental set up:

Two experimental arrangements were set up for the transmission and reception of signals in tubes. Data signals were obtained using a TTI TGA1230 30 MHZ synthesised arbitrary waveform generator and its WaveCad Software, two PZT 21 kHz transducers and petroleum jelly as coupling medium, an amplifier (40/52dB), a real time DSP board and a Tektronix digital oscilloscope of data length of 2500 samples, which were transferred via RS-232 to a computer for further processing. The excitation signal, which consisted of a chirp pulse, was designed using the WaveCad Software and downloaded in the signal generator. Two chirp signals were considered: the former with a bandwidth of 20 kHz (14 kHz-34 kHz) and pulse duration of 1 ms and the latter with a bandwidth of 1 kHz (21 kHz-22 kHz) and pulse duration of 8 ms. A real time digital filter (FIR) was designed in the DSP board with a bandwidth of 1kHz (21kHz-22kHz), Hanning filter and 512 taps. Figure 1 display the elements that comprised these trials.

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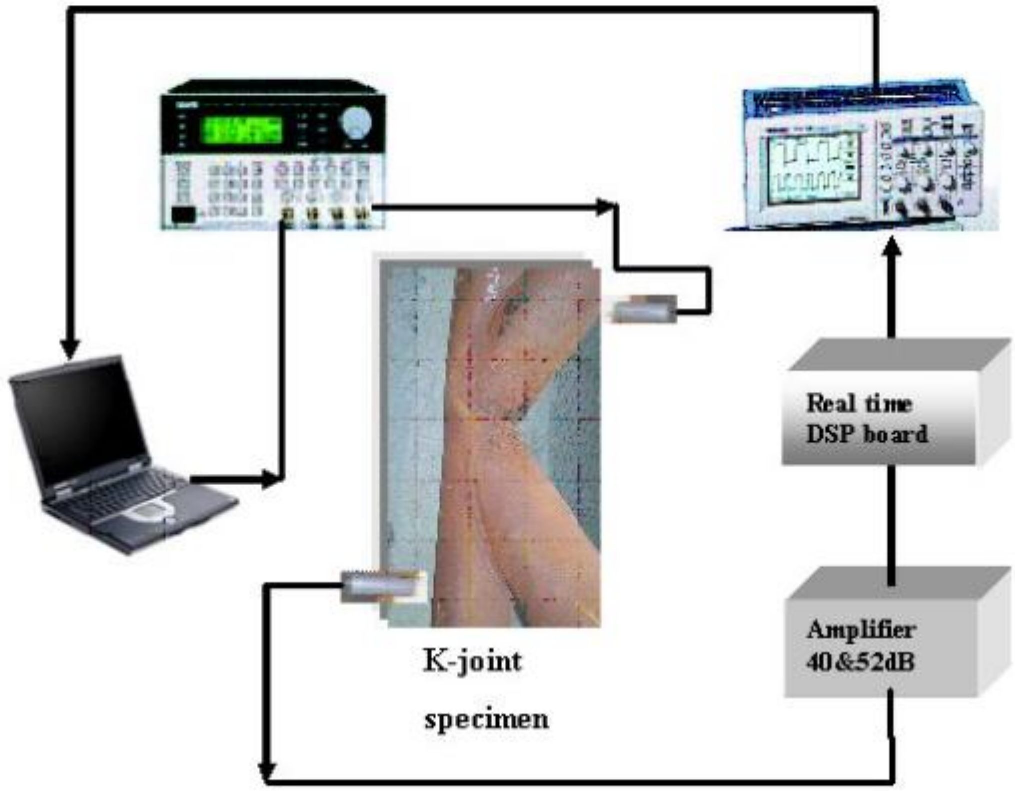

Figure 1. Experimental set up elements

Results: The first experiment depicted in figure 2a was carried out on a water loaded steel k-joints scale model of 4mX0.18mX0.007m. The transmitter was located outside at the top of one of the legs and the receiver was moved to different parts of the structure. The excitation signal was a chirp bandwidth of 20 kHz (14 kHz-34 kHz) and pulse duration of 1 ms; the attenuation (dry test) per joint was about 1.4 dB/m/joint and water loading the structure yielded an attenuation of 2.9dB/m/joint. The DSP board was not incorporated in this test. Figure 2b depicts the received signal using a gain of 52dB and transmitted chirp amplitude of 0.5V.

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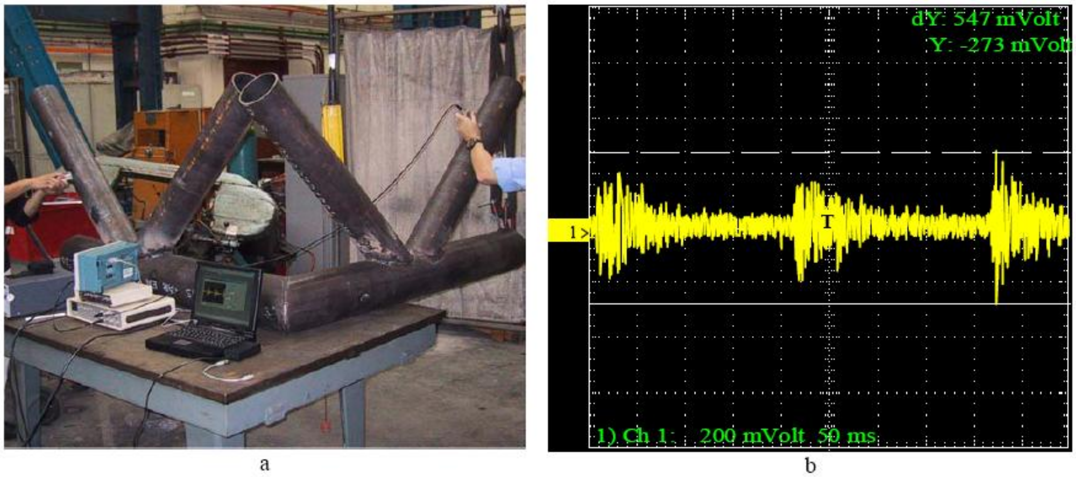

Figure 2. a) Laboratory experiment set up; b) received signal 547mVpp gain 52dB, transmitted chirp 0.5Vpp.

Overall attenuation figures could be manageable with relative low gain (52dB), however to reduce acoustic noise and increase the signal to noise ratio (SNR), a narrow bandwidth chirp signal of 1 kHz (21 kHz-22 kHz) and pulse duration of 8 ms was implemented and the real time DSP board was introduced. Transducers were located at the extremes of the k-joints (figure 2a); excitation signals as low as 5mV were identified, even embedded in noise, using a receiver gain of 40dB and performing off-line digital signal processing cross correlation. Figure 3 shows these signals.

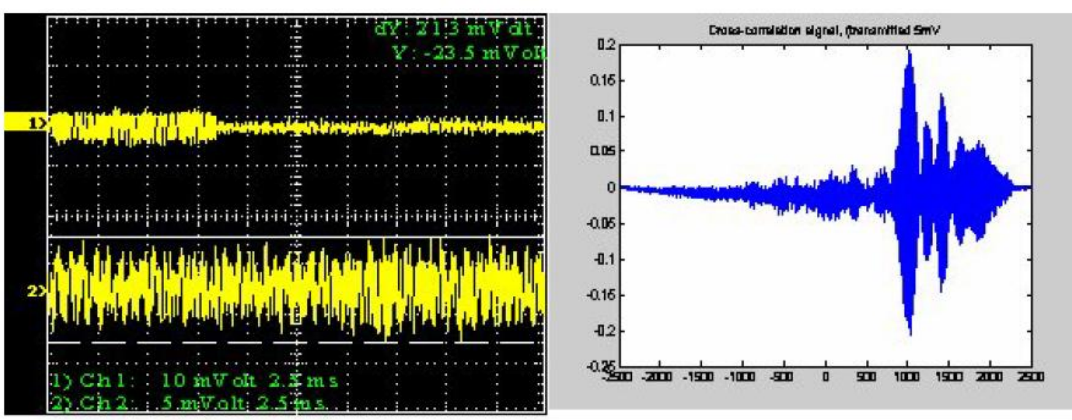

Figure 3. Left, upper trace transmitted 5mV chirp signal and lower trace received signal gain 40dB; right, chirp signal identification using off-line cross correlation.

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The field experiment, shown in figure 4, was carried out in a cylindrical bridge steel structure of 53m long and several k-joints of 0.5m-0.04m and 0.4m-0.025m diameters-thickness. Transducers were located at the extremes of the bridge and signals excitations were set to 5V.

Figure 4. Field experiment using a bridge structure of 53 m span.

Two different excitation chirp signals were used: the 20 kHz bandwidth and a gain only of 52dB and the 1 kHz bandwidth, gain 52 dB and the real time digital filtering. The former yielded signals that allowed their identification (SNR of about 6dB), however acoustic environmental noise made their reception difficult. The latter showed significant improvements of the received signal; acoustic noise was practically removed and SNR was enhanced to approximately 17 dB. Figure 5 depicts these signals.

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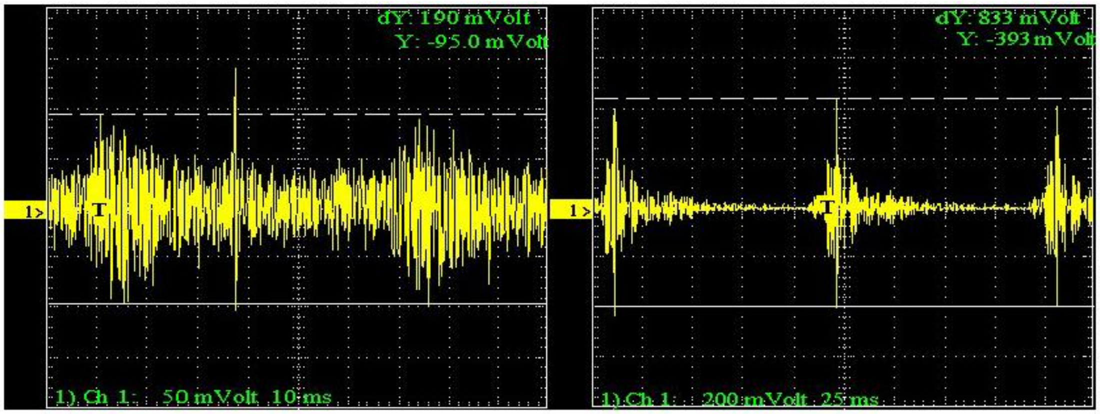

Figure 5. Left, receiver gain 52dB yielded a SNR 6dB; right, receiver gain 52dB plus 2.5dB gain in the DSP board yielded a SNR 17dB.

Discussion:

The feasibility of transmitting guided waves through steel k-joint pipes allowing for offshore oil rigs structures as a communication channel has been demonstrated experimentally via low power single monolithic PZT 21 kHz transducers using the A_0 mode. Successful transmission of low power signals of 0.005V & 0.5V and 5V was attained in the laboratory and field test respectively. Laboratory tests showed attenuation figures due to k-joints and water loading that was manageable. Narrow bandwidth chirp signals, 1kHz, and real time digital filtering enhanced the SNR of the received signals practically removing acoustic environmental noise in the large range 53m length steel pipes structure. Additionally, off-line signal processing cross correlation was performed in laboratory trials which allowed the searching of chirp signals imbedded in noise and could be considered as an important tool to be performed in real time in continuous conducting trials.

Conclusions:

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Laboratory and field experiments have been conducted using steel k-joint tubes; in which axi-symmetric A_0 guided wave modes have been encoded as chirp bursts, and transmitted and received by suitable instrumentation. Real time digital filtering algorithms and narrow bandwidth chirp signals have also been developed to minimise acoustic noise and improve the signal to noise ratio, permitting correct identification of the selected signals. As a first attempt, the transmitted information was encoded varying the time-space of transmitted pulses. Although the tests have been conducted over water loaded short k-joint steel structures (4m) and dry long range k-joint tubes (53m), attempts have been made to scale the results by using low amplitude transmitted signals. These early results are highly encouraging; however the next stage of this work is to develop a standalone waterproof transmitter and PZT transducer which have to be attached to the inner wall of a leg of a k-joint steel structure of medium range, 7-10m, and powered up by seawater activated batteries. This specimen is planned to be flooded and immersed in seawater in order to detect axi-symmetric fields due to the excitation of manageable-attenuation A_0 modes.

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