

Development of novel "Short Range Ultrasonic Guided Waves" (SRUGW) technique for lighting poles inspection

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Abstract

In this paper novel application of standard long range ultrasonic waves for short length objects has been proposed. Short Range Ultrasonic Guided Waves (SRUGW) technology for inspection of lighting poles has been investigated. The project aims to study the response of artificial defects in the near zone and conceptualize procedure for its deployment in the field. In order to size defects the sensitivity and shadowing curves has been calculated. Finally in order to minimise the dispersion effect and improve the determination of defect's position modern adaptive approach for time-frequency decomposition called Matching Pursuit (MP) has been applied and results has been discussed.

1. Introduction

The paper aims to harness the power of long range ultrasonic technology for inspection of short length objects and to study the response of artificial defects in the near zone and conceptualize procedure for its deployment in the field. The focus of the project is inspection of lighting poles due to relatively limited number of material and size variations and due to the huge number of field applications. The non-destructive testing equipment to be used for the project called MsS has been developed by SWRI, USA.

Long Range Guided Waves are normally applied to piping for the detection of corrosion. This technology identifies features in the piping which correspond to an increase or a decrease in the pipe wall thickness. Once this effect has been identified, the axial position along the length of the pipe can be determined. It is always necessary to perform a secondary inspection with other Non-Destructive techniques to determine the nature of the feature, but having an identified axial location greatly reduces the extent of this secondary inspection necessary to accurately interpret the condition of the pipe. Long range ultrasonic technology, which essentially uses longitudinal waves generated by a number of piezoelectric transducers arranged spatially to flood the volume of the component with ultrasonic energy is well known⁽¹⁾. The defect detection capability of guided wave ultrasound is not affected by presence of bends, welds, distributaries etc. However the amount of ultrasonic energy reflected from a defect is affected by the fluid through piping, covering over piping etc. SWRI USA has developed a new guided wave ultrasonic technology based on principle of magnetostriction, which applies non-dispersive torsional waves. MsS technology

requires bonding a strip of magnetostrictive material to the part under test and using a simple single transducer for transmission of ultrasonic energy.

In this paper novel application of standard long range applications for short length objects has been proposed. Short range ultrasonic guided wave (SRUGW) technology for inspection of lighting poles has been investigated. In order to size defects the sensitivity and shadowing curves have been computed. Finally modern adaptive technique for time-frequency decomposition called Matching Pursuit (MP) to analyze signals generated by the sensor has been applied and results has been discussed.

2. Experiment

2.1 MsS Instrument, magnetostrictive sensor

On the Fig.1, on the left, a thin strip of magnetostrictive material (Nickel or similar material) bonded to the pipe to be inspected is shown. The strip is then conditioned by aligning the magnetic domains in axial direction. A coil is then placed over this conditioned strip, and connected to the MsS Instrument (Fig.1 on the right). When the instrument is energised, the coil carries a specific frequency and duration of current, which momentarily electro-magnetically aligns the magnetic domains in the strip to the direction of sound propagation. This re-alignment produces a change in dimension of the strip, which coupled through the epoxy bonding creates a torsional ultrasonic wave in the pipe. This wave can be adjusted in frequency and direction with the instrument. In this work 8-cycle pulse with centre frequency of 128 kHz has been used.

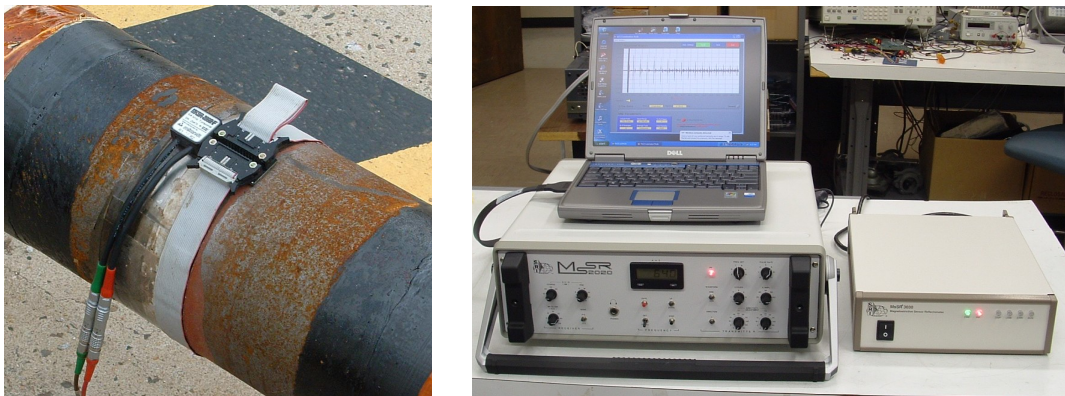


Figure 1. Magnetostrictive sensor on the left and MsS instrument on the right

2.2 Pipe specimens

Most commonly used pipe sizes for making lighting poles were determined from “Specifications for Street Lighting – Residential and Industrial Estates – Specifications” published in 2005 by Durham County Council. For the inspection 4.5 inch diameter, 7.5 m long and 10 mm thick pipe was selected.

2.3 Measurement procedure

Long Range Ultrasonic Testing (LRUT) generates a low frequency ultrasound wave which travels along the length of a pipe, detecting “significant” defects and other features. Significant corrosion, welds and fittings will also generate signals or attenuate signals, so interpretation of these signals is important to provide maximum information. In order to study the difference in response from reference defects in the presence of other defects the following method was applied. First hole was made at 0.5 m distance from the end of the pipe with respectively: 3.5, 5.0 and 8.5 mm diameter. Then, next hole with the same diameters was created at 0.5 m with respect to previous hole and shifted on pipe's surface about 45°. Total number of the holes is 9. The test pipe with 4 shifted artificial defects has been shown in Fig. 2.



Figure 2. Test pipe with 4 shifted artificial defects

2.4 Results

Fig. 3 below (Left) shows sensitivity for three different hole sizes. The plot clearly shows the amplitude variations in the near zone. The amplitude of the signal from 5.0 mm diameter hole and 8.5 mm diameter hole are seen to be same.

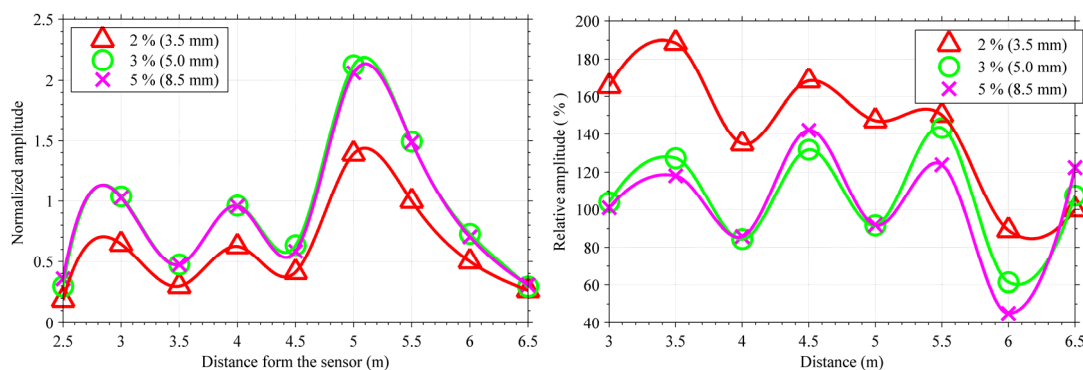


Figure 3. Sensitivity analysis plot on the left and shadowing effect on the right

In the plot shadowing effect (Fig. 3 on the right) clearly shows that the effect of presence of defect in front of the defect being characterized is a non-linear function of the defect size and its location.

3. Data analysis

3.1 Introduction

There are number of ultrasonic signal modes which depend on material structure and frequency of the signal. Some of these modes are dispersive while others are non-dispersive. Although in the experiment non-dispersive torsional mode has been applied, other modes (mode conversions) usually can appear due to interaction of ultrasonic energy with the structure and defects. These additional modes appearing in received signal disturb recognition of the defects and significantly reduce signal-to-noise ratio. Therefore, it is essential to distinguish all the reflections from the signal. Simple signal processing analysis such as low or high pass filters cannot be applied since dispersive wave modes occupy the same bandwidth as the signal of interest. Apart from filters there are several time-frequency techniques which allow to minimise this dispersion phenomena such a wavelet de-nosing^(2,3) or other specialized signal processing techniques, which use *a priori* knowledge of the dispersion characteristics of guided wave mode to map signals from the time to distance domain^(1,4).

All these methods have both advantages and disadvantages. We propose to use of a modern adaptive time-frequency filtering called Matching Pursuit (MP). Matching Pursuit algorithm is alternative approach for time-frequency decomposition of pulse-echo signals. Its advantage is that it creates a concise signal approximation with the help of a small set of Gabor (Gauss functions) atoms (components) chosen from a large and redundant set. It creates a concise description of the analyzed signal with a small number of components represented by only a few parameters and precisely located in the time-frequency space^(5,6).

3.2 Method

Matching Pursuit enables the creation of signal approximations with a small number weighted vectors $g_{\gamma_n}(t)$ chosen from a set⁽⁶⁾:

$$f(t) = \sum a_n \cdot g_n(t), \quad (1)$$

where: a_n - coefficients, $g(t)$ - Gauss functions.

These Gauss functions simply scaled, translated and modulated and are called the time-frequency atoms⁽⁶⁾.

$$g_{\gamma_n}(t) = \frac{1}{\sqrt{s_n}} \cdot g\left(\frac{t-u_n}{s_n}\right) \cdot \exp(j\zeta_n t), \quad (2)$$

$\gamma_n = (s_n, u_n, \zeta_n)$, s_n - scale, u_n - translation, ζ_n - modulation, $g(t) = \sqrt[4]{2} \cdot \exp(-\pi \cdot t^2)$ - Gaussian window.

At the beginning MP is searching the dictionary for an atom g_{γ_0} correlated best with the signal f . That means that this atom has the biggest inner product with the signal of all dictionary atoms. Then the signal f is represented as:

$$f = \langle f, g_{\gamma_0} \rangle g_{\gamma_0} + Rf, \quad (3)$$

where Rf is the residual vector after approximating f in the direction of g_{γ_0} . Next, the best correlated atom with the residuum Rf is found:

$$Rf = \langle Rf, g_{\gamma_1} \rangle g_{\gamma_1} + R^1 f \quad (4)$$

If we set $R^0 f = f$, then in general case following formulae can be written:

$$R^n f = \langle R^n f, g_{\gamma_n} \rangle g_{\gamma_n} + R^{n+1} f \quad (5)$$

This algorithm is repeated until the desired approximation of energy level is reached. In this case it is 95% of the total signal energy. Finally the signal f is represented by:

$$f = \sum_{n=0}^{m-1} \langle R^n f, g_{\gamma_n} \rangle g_{\gamma_n} + R^m f \quad (6)$$

For real signal f a real time-frequency atoms must be used in order to get a decomposition with real expansion coefficients. In principle, the dictionary of time-frequency atoms is infinite, however to limit the computation time dyadic scheme has been applied:

$$\gamma = (s, u, \zeta) = (a^i, pa^i \Delta u, ka^{-i} \Delta \zeta), \quad (7)$$

where $a = 2$, $\Delta u = 0.5$, $\Delta \zeta = \pi$, $0 < i < \log_2 N$, $0 \leq p < N2^{-i+1}$, $0 \leq k < 2^{i+1}$, (N - signal length)

Searching this subspace the rough values of the best matching atoms' parameters can be found. Then, to get the best matching atom, these parameters are refined by using arbitrary maximisation method. The MP algorithm has been implemented in MATLAB[®] environment, and as a maximisation method the *fminsearch* function has been applied.

3.3 Numerical results

Data to this section were taken from the experiment considered in previous paragraph. In Fig. 4, on the left, the original signal (finger print) of the pipe recorded from the sensor has been shown. Plot on the right shows signal from the pipe which includes echoes from 9 drilled holes with 8.5 mm diameter (5% of the pipe cross section area). The magnetostrictive sensor was located at 0.5 m distance to the pipe end (at 0 m on x -axis in the plots).

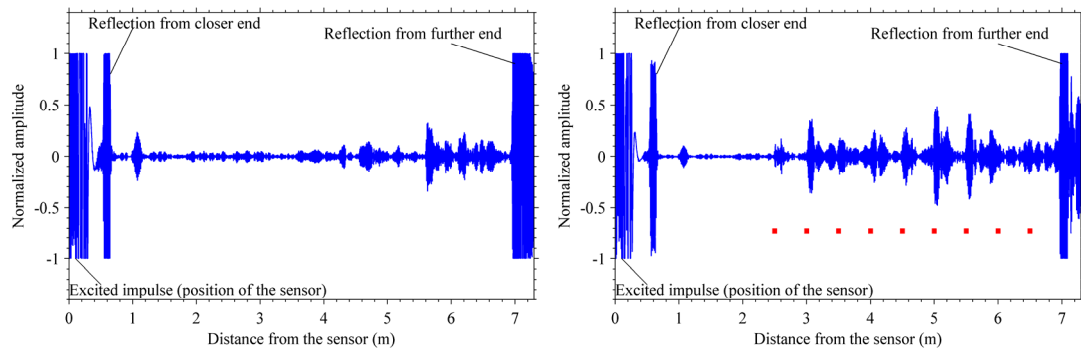


Figure 4. Finger print of the pipe one the left; ultrasonic signal which includes echoes from 9 drilled holes on the right; red dots show physical position of the defects

Although the reflections referred to the some of the 9 artificial defects can be observed, it is very difficult to distinguish them precisely from the signal. In Fig.5 and Fig. 6 Matching Pursuit analysis for signal recorded from the pipe with 6 artificial defects has been shown. In Fig. 7 and Fig. 8 the same analysis was made for the pipe with 8 defects.

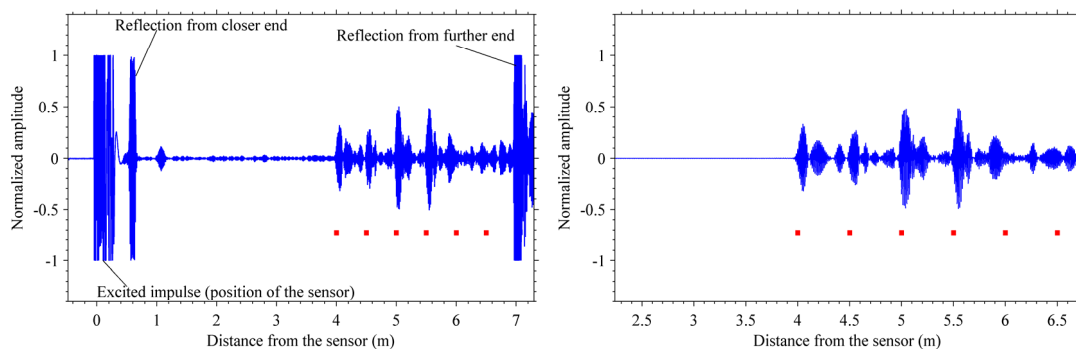


Figure 5. Signal from sensor with 6 defects on the left; on the right signal limited to the 2.3 - 6.7 m range and approximated by 32 atoms (corresponds to 95% signal energy); physical positions of the defects marked by red dots

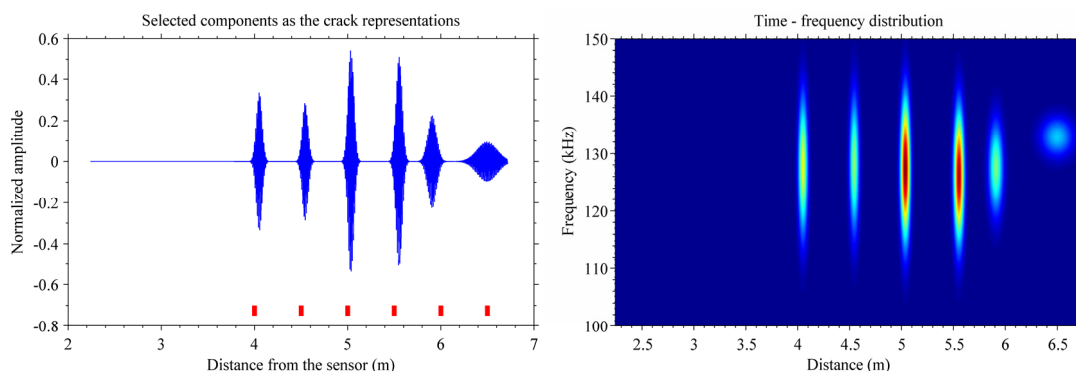


Figure 6. On the left selected atoms, which correspond to the reflections from 6 defects; on the right their time-frequency distribution

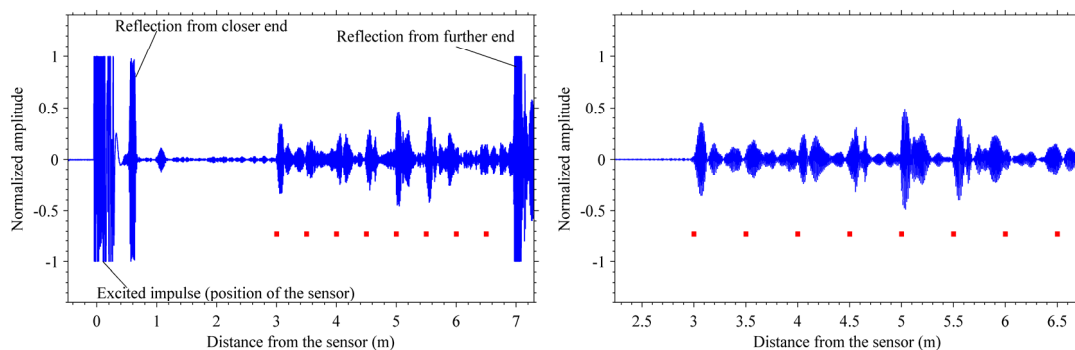


Figure 7. Signal from sensor with 8 defects on the left; on the right signal limited to the 2.3 - 6.7 m range and approximated by 25 atoms (corresponds to 95% signal energy); physical positions of the defects marked by red dots

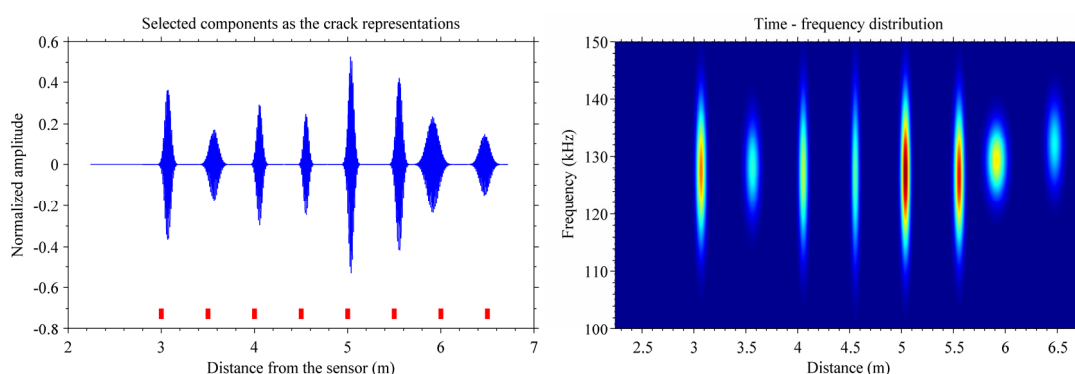


Figure 6. On the left selected atoms, which correspond to the reflections from 8 defects; on the right their time-frequency distribution

From the above plots it can be observed that the atoms' shapes representing defects in most cases have got short duration in time domain and contain similar bandwidth. The different shapes for two furthest defects (closest to the pipe far end) can potentially be attributed to the interference from the finger print of the tube.

3. Conclusions

The experimental work has demonstrated that defects can be detected in short pipes by using long range ultrasonic guided waves technology (MsS). The defects can be sized with the help of calibration curves (Fig. 3). If the shadowing effect due to the presence of preceding defects / features does not exist, then the defects are sized correctly. If the shadowing effect exists the defects can be detected but their sizing is very difficult because of mode conversions and because of the presence of other defects. In order to minimise the dispersion effect and improve the determination of defect's position modern adaptive approach for time-frequency decomposition called Matching Pursuit (MP) has been applied. This signal analysis has shown, that it is possible to distinguish all the ultrasonic signals reflected from the defects, however the durations and the bandwidths do not need to be always exactly the same, particularly when taking into account signal finger print of the pipe. Important limitation of the proposed method is

time required for the computation signal's approximation, especially when the original signal is very noisy.

Acknowledgements

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