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LOCATION SPECIFIC TEMPERATURE COMPENSATION OF GUIDED WAVE SIGNALS

Stefano Mariani[1], Peter Cawley
Imperial College London
London, U.K.

ABSTRACT

The baseline subtraction method is widely used to detect defect signatures in guided wave structural health monitoring. In essence, an earlier measurement is subtracted from the 'current' signal, and high residuals might indicate damage occurrence. However, varying environmental and operational conditions, such as temperature, also produce signal changes and hence, potentially, high residuals. A number of temperature compensation methods have been developed, which typically targets the varying wave speed due to varying temperature. Nevertheless, other, subtler effects caused by temperature variations are often overlooked, such as changes in attenuation, in the transducer frequency response and in the relative amplitudes of different modes excited by the transducer. A novel temperature compensation procedure is developed, which corrects any spatially dependent signal change that is a systematic function of temperature, hence producing residuals less affected by temperature variations. This new method was applied to a set of T(0,1) guided wave signals collected by a pipe monitoring system, yielding residuals reduced by at least 50% compared to those obtained using the standard approach at positions away from structural features, and by more than 90% at features such as the pipe end. The method therefore promises a substantial improvement in the detectability of small defects, particularly at existing pipe features.

Keywords: baseline subtraction, defect detection, guided waves, pipe inspection, temperature compensation.

1. INTRODUCTION

Inspection systems based on guided waves are widely used to detect damage in numerous applications, such as the testing of pipes for the oil & gas industry by means of the T(0,1) torsional wave mode using a pulse-echo configuration at frequencies in the order of tens of kHz [1]. In this setting, the sensor is deployed on the structure and it is then removed after taking one (or a few) measurements. Unfortunately, in addition to the desired T(0,1) mode, other signal components exist due to imperfect direction control [1] and to the excitation and reception of unwanted modes. The latter is partly due to the finite number of transducers generating tangential forces at discrete locations rather than uniformly around the external circumference of the pipe, and also due to an unavoidable non-uniform transduction sensitivity of the transducers around the circumference. Because these unwanted signal components are deterministic, they cannot be eliminated through averaging and hence they set a background noise level which is referred to as coherent noise.

Recently, there has been strong interest in moving from the standard one-off inspection configuration to a permanently installed monitoring system (PIMS), which allows for frequent collection and interpretation of data [2], hence potentially enabling the detection of damage at earlier stages. Recent publications presented examples of such systems based on piezoelectric transducers [3, 4], Lorentz force–based EMAT transducers [5] and magnetostrictive-based EMATs [6].

In a PIMS setting, the data analysis typically involves comparing new measurements with a baseline record, where any change in the signal could represent a defect signature, in a procedure termed baseline subtraction [7]. Unfortunately, changing environmental and operational conditions (EOCs), primarily temperature [8], also cause changes in the signals, so degrading the damage detection performance. A possible solution to the problem would be the early collection of a large number of baselines acquired under different EOCs, followed by selection of the best one to subtract from any later reading, in a procedure called optimal baseline selection (OBS) [9-10]. However, such a solution is often impractical as a very large number of baseline signals is required at small increments of operating condition [11]. Another widely used technique is the baseline signal stretch (BSS) [9, 11-12], which compresses or dilates the 'current' signal to compensate for the temperature-induced change of velocity of the primary guided wave mode [8]. This process captures the physics of the effect of temperature changes well except that the process of time-stretching slightly distorts the frequency content of the signal, an effect that is termed 'frequency noise' [13].

[1] Contact author: s.mariani@imperial.ac.uk

However, there are other, less-studied, effects caused by temperature variations on the wave propagation. For instance, a change of temperature typically induces changes of the frequency response of the transducers that can affect both the amplitude and the phase of the signal [11]. Additionally, if the system is operated close to resonance, a ringing effect may be observed at some temperatures. Recently, the authors proposed a phase compensation procedure that concurrently targets wave speed and transducer phase response changes, here denoted as the phase and stretch compensation (PSC) procedure [14]. Importantly, any change to the balance of transduction around the pipe or to the transducer frequency responses is likely to alter the generation of unwanted flexural and circumferential modes and so modify the coherent noise in a way that is not corrected by previous temperature compensation methods. Also, some applications of guided wave-based monitoring systems are affected by strong signal attenuation, which is usually temperature dependent, for example monitoring of a pipe coated with a viscoelastic material such as bitumen.

A novel procedure that will be called the location specific temperature compensation (LSTC) method has been developed specifically to target these and other effects. This new method was applied to a pipe PIMS employing the T(0,1) wave mode. The final goal of the method is to minimize the residual obtained at each location in the structure, so that in the absence of a defect, the residual will be close to zero, making it easier to detect the presence of any signal changes produced by a defect.

2. EXPERIMENTAL SETUP

The method was tested on a dataset of ultrasonic guided wave signals acquired by a PIMS set to use the T(0,1) wave mode. The sensor ring was attached to an 8 inch schedule 40 pipe whose layout is shown in Figure 1 and which was installed in a temperature controlled laboratory setting [3]. The excitation was an 8-cycle toneburst centered at 25.5 kHz. The pipe comprised 7 m and 2 m straight sections connected by a 90° elbow (with a bend radius of 1.5 times the outer diameter of the pipe), and the sensor was installed 4.5 m from the right hand end in the figure. In addition to the elbow welds, there was a girth weld in the longer straight section of the pipe. The measurements used to perform the analysis reported in this article are the ones in the 'forward' direction as indicated in Figure 1. The pipe was subjected to heating and cooling cycles, with the temperature fluctuating between about 13°C and 38°C.

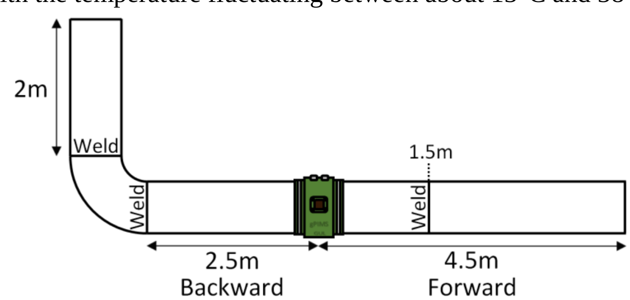

FIGURE 1: GEOMETRY OF THE 8 INCH SCHEDULE 40 TEST PIPE.

3. RESULTS AND DISCUSSION

Figure 2 compares the residuals obtained using the standard baseline subtraction method with PSC temperature compensation to the ones resulting from the application of the new LSTC method; in each plot, a total of 252 signals are overlaid on top of each other. In Figure 2(a), very high values of residuals (clipped at this zoom level) are seen at the pipe end; since both the baseline and 'current' signals contain large components of the pipe end reflection, baseline subtraction involves subtracting two large quantities and so is very sensitive to environmentally induced signal changes. These include frequency response changes of the transducers, such as ringing effects and the 'frequency noise' as discussed above. In Figure 2(b), the residuals output by the LSTC method are lower than those obtained by the standard baseline subtraction, with more than an order of magnitude improvement at the pipe end.

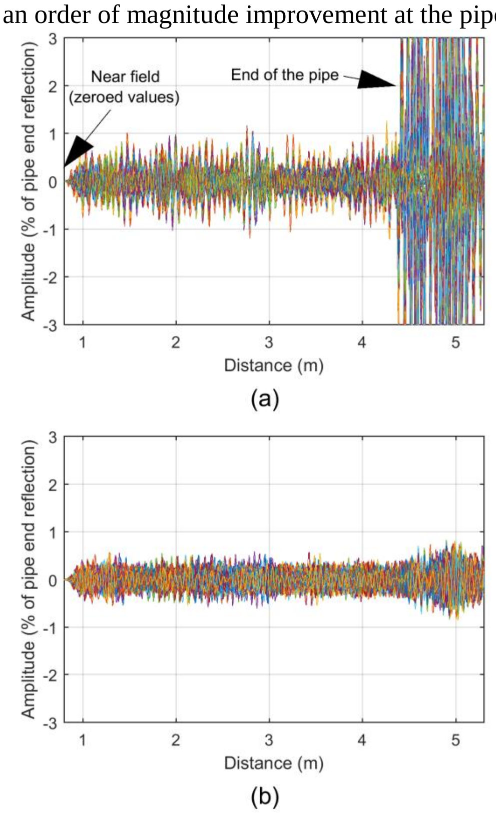

FIGURE 2: TESTING ON THE "FORWARD" DIRECTION OF FIGURE 1. RESIDUAL SIGNALS OBTAINED USING (A) THE STANDARD BASELINE SUBTRACTION METHOD WITH PSC TEMPERATURE COMPENSATION, AND (B) THE NEW METHOD.

4. CONCLUSION

The new LSTC method enabled reduction of residuals to below 0.6% of the pipe end reflection at locations away from the pipe end meaning that defects removing around 1% of the cross sectional area would be detectable in a single test, with further improvements likely using multiple readings [3], [15].

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