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Tom Druet, Axel Thomas, Arnaud Recoquillay, Yann Gélébart, Etienne Martin, et al.. Passive guided wave tomography for corrosion monitoring under varying environmental conditions. 2nd International Conference on Non-Destructive Examination in Nuclear (NDE in Nuclear 2023), Jun 2023, Sheffield, United Kingdom. 28283 (6 p.), 10.58286/28283 . cea-04189381

HAL Id: cea-04189381

<https://cea.hal.science/cea-04189381>

Submitted on 28 Aug 2023

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Guided Wave Tomography for Corrosion Monitoring under Varying Environmental Conditions

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Abstract

This paper presents a study of guided wave tomography for corrosion monitoring under varying environmental conditions. Guided wave tomography can be computed in an ‘absolute’ mode thanks to an automatic calibration using solely the data of the current acquisition. This is interesting because no baseline is needed. In particular, this paper studies the capacity of absolute tomography algorithms to be robust to temperature fluctuations. Experimental validations of the method are presented and results on the method’s robustness to temperature variations are shown through acquisitions carried out in a climate chamber over a wide range of temperatures.

Keywords: structural health monitoring, guided wave, tomography, temperature, environmental and operational conditions

1. Introduction

The detection and quantification of defects in structures by non-destructive testing techniques plays a crucial role in several industries. Once a defect is detected, assessing its severity enables to schedule maintenance appropriately, hence reducing rupture or leakage risks.

Structural Health Monitoring (SHM) is an approach that consists in instrumenting a structure with permanent sensors to monitor its health status throughout its life. Guided elastic waves are particularly suitable for SHM applications on thin structures thanks to their ability to propagate over long distances and their high sensitivity [1]. They can be used in many cases such as plate-like [2], pipe-like [3,4] or rail-like structures [5], enabling to inspect a large area in a single acquisition and thus limiting the needed time or number of sensors. In this paper, guided waves are used to monitor corrosion in plates. However, guided waves are sensitive to Environmental and Operational Conditions (EOCs) [6] like temperature. This sensitivity hinders the applicability of most methods, which use a baseline that needs to be taken with the same EOCs to limit false alarms. Some methods in the literature such as Baseline Signal Stretch (BSS) [7] enables to compensate these variations, but only up to a few degrees in the case of temperature. We work since several years on guided wave tomography [8,9] applied to SHM for the detection and quantification of corrosion. In that context an automatic calibration method using solely the data of the current acquisition has been developed so that tomography does not need a baseline in the calibration step [10]. It allows to obtain absolute and precise maps of the thickness of an area surrounded by a distribution of sensors. The type of corrosion defects imaged by this technique is generalized corrosion, leading to thickness losses on extended areas of size typically higher than the centimeter.

This paper presents the capacity of absolute tomography algorithms to monitor corrosion under varying environmental conditions in plates. Controlled temperature variations are studied thanks to the use of a climate chamber. An analogue study has been performed on pipes using the natural warm-up of the structure due to an air/sand flow inside the pipe [11]. In this paper, a comparison of the effects of temperature on absolute and relative tomography is performed in order to show that the use of a baseline can lead to a bias in the reconstruction of the defects. We will finally see that absolute tomography appears to be a very attractive method compared

to relative tomography to assess the real remaining thickness of the structure in case of varying environmental conditions.

2. Experimental setup

In order to evaluate guided wave tomography under varying environmental conditions, a climate chamber enabling to change and stabilize the temperature while acquiring data for imaging is used (see Figure 1). A range of 70°C is covered, starting from -20°C and ending at 50°C with 10°C steps.

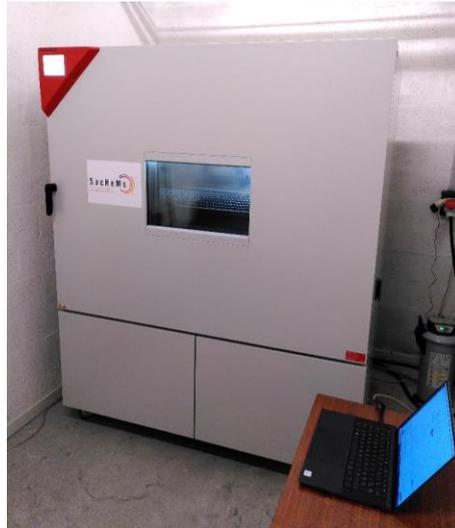


Figure 1: Climate Chamber.

A 3mm thick aluminium plate is instrumented with 48 piezoelectric transducers that are glued on the plate (see Figure 2) using epoxy. The circle of transducers has a diameter of 30cm. For the emission, a Hann burst of 5 cycles at 50 kHz is used. For that specific frequency, the wavelength is about 23.1mm for A_0 mode which is used to perform guided wave tomography images presented later in this paper. The dispersion curves for the group velocity are also presented in Figure 2 for a temperature of 20°C. Note indeed that the dispersion curves of the guided modes will depend on the EOCs, especially the temperature, hence the sensitivity of guided wave methods.

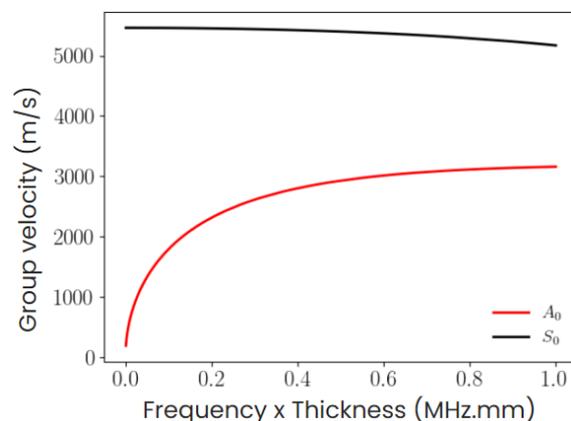
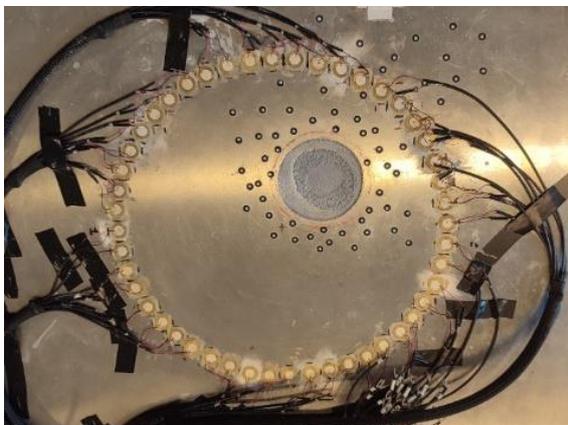


Figure 2: Instrumented aluminium plate and dispersion curves of A_0 and S_0 modes.

Regarding the defects, electrolysis is used to create erosion defects in the aluminium plate. Three different defects are created thanks to elliptic masks that allow to obtain more complex geometries than simply circles. These masks and the third defect are presented in Figure 3.



Figure 3: Elliptic masks and third defect created by electrolysis.

In order to get a reference of these three defects, a structured light 3D scanner (Go Scan system) is used. This allows to assess the quality of guided wave tomography images later in this paper. The three references corresponding to the three defects are presented in Figure 4.

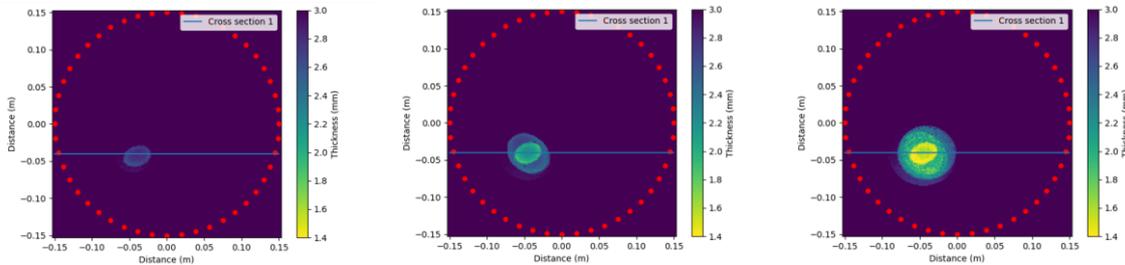


Figure 4: The 3 reference maps measured by 3D scanner.

3. Results

Guided wave tomography under varying temperature is studied in this section. The objective is to evaluate how temperature can affect the performances of absolute tomography and then assess to what extent absolute tomography is more robust than relative tomography due to the fact that absolute tomography does not rely on a baseline.

2.1 Absolute tomography at ambient temperature

We first start with absolute tomography at ambient temperature, i.e. 20°C. This first study gives an idea of the behaviour of the algorithm when the temperature is the same for the acquired signals and the computation of the dispersion curves. The results are presented in Figure 5. The tomography images contain a constant background noise of about 0.2mm no matter how deep the defect is. By comparing these results to the Figure 4, the global size of the defects are well retrieved and the remaining thickness is well estimated for the three cases. In the next studies of this paper, cross sections are plotted to allow a better visual comparison. This cross section corresponds to the blue line of Figure 5.

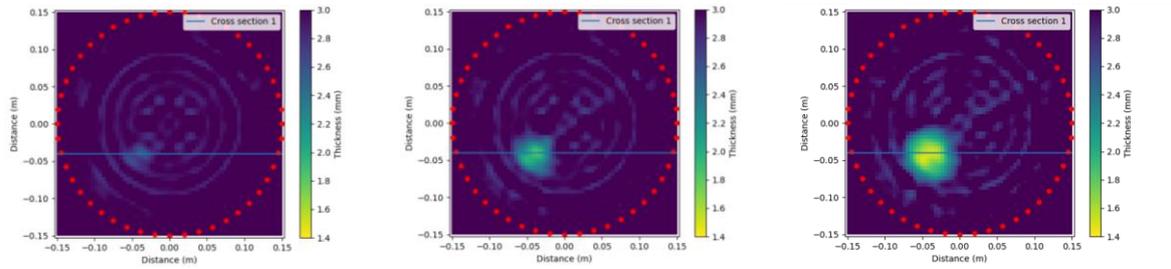


Figure 5: The 3 absolute tomography results for the nominal temperature 20°C.

2.2 Absolute tomography under varying temperatures

Now that we have checked that absolute tomography gives good results on the three defects, we present absolute tomography cross sections for all temperature levels, i.e. starting from -20°C and ending at 50°C with 10°C steps. Those results are presented in Figure 6. Once again we retrieve that the global shape and the minimal remaining thickness are well estimated. More interesting is that whatever the temperature, the defect reconstruction is of good quality. Absolute tomography seems to compensate intrinsically a part of the effects of temperature thanks to the use of the autocalibration method [10].

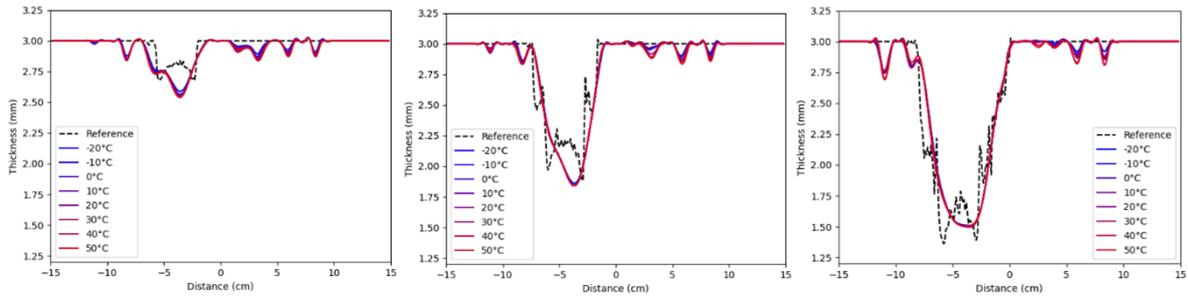


Figure 6: The 3 absolute tomography cross sections for all the temperature levels.

Nevertheless, absolute tomography and more precisely the autocalibration method does not compensate for all the effects. In order to study more in details the remaining effects, two zooms in are performed on the cross section of the deeper defect: one on the defect and one on the image background (see Figure 7). In both cases, when the temperature increases the estimated thickness decreases. This can be explained as follows: an increasing temperature implies a decrease in stiffness (or Young's modulus) which implies a reduction in speeds, including that of mode A0. In addition, a decrease in the speed of the A0 mode translates into a decrease in thickness (see dispersion curve of A0 mode in Figure 2) which means that, overall for the A0 mode, an increase in temperature can be interpreted as a decrease in thickness. However, the remaining variations are of the second order compared to the real thickness of the defect and the precision of the algorithm, which is of the order of the tenth of millimeter.

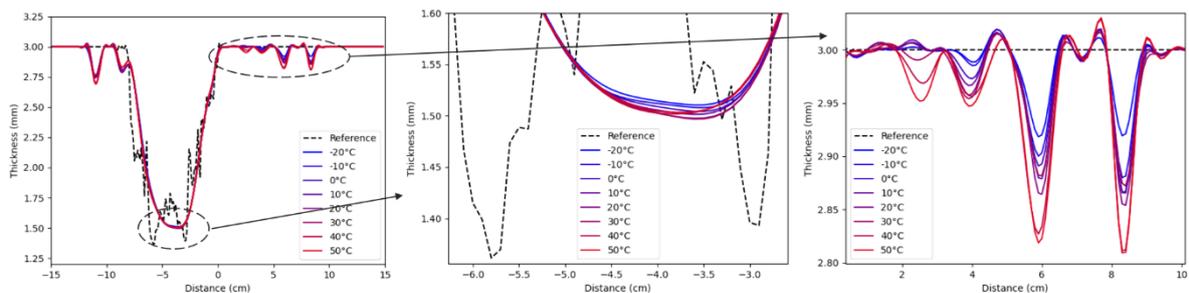


Figure 7: Zoom in on defect and image background.

2.3 Proof of the robustness of absolute tomography compared to relative tomography

In that final section, relative tomography is tested. This is interesting because relative tomography needs a baseline to calibrate the data and it is known in the literature that, for some guided wave imaging algorithms, the use of a baseline can become obsolete if it is not coherent with the EOCs of the current state. Thus, it is interesting to study that in the case of guided wave tomography.

The same cross sections and the same temperature levels that for absolute tomography are studied. The baseline used to calibrate the relative tomography corresponds to the data measured at -20°C . The results are presented in Figure 8. By comparing the cross sections with the ones of Figure 6, we find that in relative tomography a bias in the reconstruction occurs when the baseline is measured at a different temperature from the current state. Thus, absolute tomography appears to be a very attractive method compared to relative tomography to assess the real remaining thickness of the structure in case of varying environmental conditions.

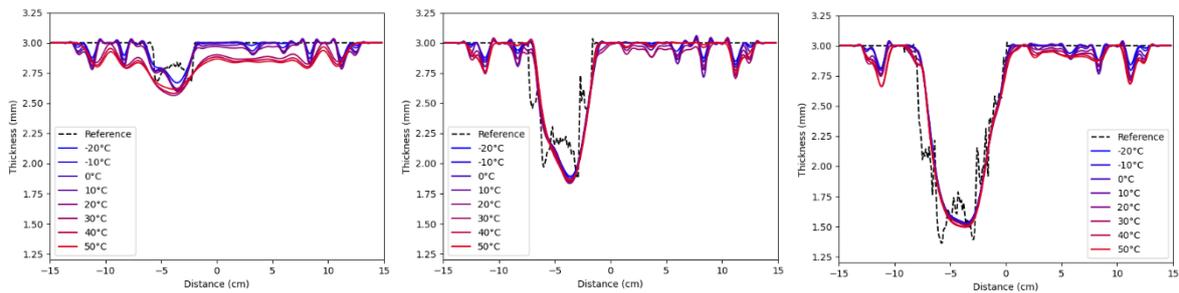


Figure 8: The 3 relative tomography cross sections for all the temperature levels.

3. Conclusion

To conclude, in this paper guided wave tomography performances have been evaluated for large temperature variations, i.e. from -20°C to 50°C with 10°C steps. It appears that absolute tomography is robust to those EOC variations and seems to compensate intrinsically a part of the effects of temperature thanks to the autocalibration method. In comparison, a bias in the reconstruction occurs for relative tomography when it uses a baseline for data calibration that is measured at a different temperature from the current state. This confirms that an obsolete baseline, due to variations of EOCs, can introduce a bias in relative tomography whereas absolute tomography still gives a good estimation of the defect, as it does not use a baseline, even if the used dispersion curves were computed using reference EOCs.

In any case, absolute tomography appears to be a very reliable method to assess the real remaining thickness of the structure evolving in varying environmental conditions. The next stages of the study will consist in performing the same kind of analysis on more complex structures, typically pipes with welds and supports, in a real environment.

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