Model Based Optimisation Of Non-Destructive Inspections

Introduction

Non-destructive testing is the notion of using non-invasive methods, such as ultrasound and x-rays, to inspect the internal structure of equipment to find damage. The development of these methods and the validation of their capability, referred to as qualification, typically involves producing a range of sensors to quantify the effect of variations in their design and a large number of defect specimens with variation in parameters such as defect location, size and morphology to assess the inspection's capability to detect a range of defects. This can be an immensely costly and time consuming process, resulting in the process being prohibitive. This has been identified as a major barrier to the introduction of new inspections into service.

One method of alleviating this costly burden is to replace the vast majority of these experimental trials with the results of numerical simulations of the same scenarios. This has the potential to significantly reduce the cost of development and qualification and accelerate their introduction into service. This document provides an overview of the application of a model based approach to the development and optimisation of an ultrasonic inspection.

Optimisation of Ultrasonic Thickness Sensors for Corroded Pipes

The corrosion of pipework is a common deterioration across a broad range of industries, from aerospace through oil and gas and into nuclear. Detecting patches of corrosion and quantifying the remaining wall thickness of the pipe is essential to prevent a potentially catastrophic rupture. In the oil and gas industry, given the vast quantity of pipelines laid across the world, it is immensely expensive to have humans undertake regular inspections across an entire pipeline network. There is, therefore, a trend towards low cost, permanently installed sensors which do not require human operation and can provide regular, repeatable measurements to monitor the health of a system, Structural Health Monitoring (SHM).

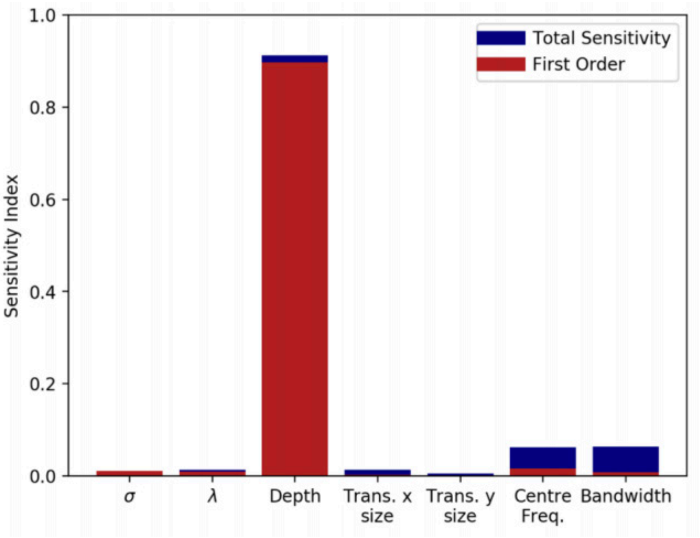

FIG. 1. The sensitivity indices for each of the seven parameters: the mean amplitude of the corrosion σ, the correlation length of the corrosion λ, the mean depth (or thickness) of the pipe wall, the x and y side length dimensions of the sensor and the centre frequency and bandwidth of the sensor. The first order index refers to the direct effect of varying the single parameter and the total sensitivity accounts for interaction between parameters.

The use of ultrasonic measurements in a pitch-catch configuration, using a single sensor which transmits a pulse of ultrasound and listens for reflections, is a well established technique for measuring the thickness of pipe walls. The sensor however has a range of variables which can be tuned to maximise the efficacy of the inspection. A fully parameterised 3D, finite element simulation of the inspection was implemented with varying sensor parameters, such as size and operating frequency, pipe thickness and corroded surface profiles. The amplitude of the first reflection was used as the response of the inspection as typically used in industry. The initial investigation focussed on the determination of the sensitivity of the response to the various parameters, specifically using Sobol indices to calculate the proportion of the variance of the response that can be attributed to variations in each parameter. The results of this are shown in Figure 1. This shows that the response is most sensitive to changes in the thickness of the pipe wall, is very insensitive to the parameters that describe the corrosion and the dimensions of the transducer, and some appreciable sensitivity to the centre frequency and bandwidth of the sensor. This provides strong evidence that this is a good inspection for determining the remaining thickness of the pipe wall as changes in this induce the largest changes in the response of the inspection. This information can be used as part of a qualification campaign to demonstrate the suitability of an inspection technique for a given inspection challenge.

This information can be used to optimise the sensors to most accurately determine the remaining pipe wall thickness. The sensitivity analysis has shown that the size of the transducer is not important therefore this can be ignored from the optimisation, thereby reducing the computational burden. Therefore, the two parameters that will be optimised are the centre frequency and bandwidth of the transducer. In the ideal case, there would be a perfect correlation between the measured depth and the real depth, if you plot one as a function of the other you would expect a perfect straight line of gradient one. Assessing how close the measurements are to this line gives a measure of how optimal the sensors are. The results of applying this process are shown in Figure 2. This shows that a good sensor with only small errors in the determination of the pipe wall thickness is achievable. The robustness of this optimal configuration can be investigated by computing and plotting the optimality criterion as a function of the two parameters. This is shown in Figure 3. This demonstrates that the optimal value is very stable and that approximately half of the parameter space, the upper left half of Figure 3, is within 4% of the optimal value. From a manufacturing point of view, this gives very large tolerances on the production of these sensors whilst still obtaining very high performance, that is being able to accurately determine the remaining pipe wall thickness.

This project used significantly less resources than a typical qualification campaign and did not require the manufacture of large numbers of sensors and specimens. The models and code used in this work can be reused should these sensors need to be optimised for another application. This ability to reuse the previous work further reduces the cost and time for future optimisation and qualification problems.

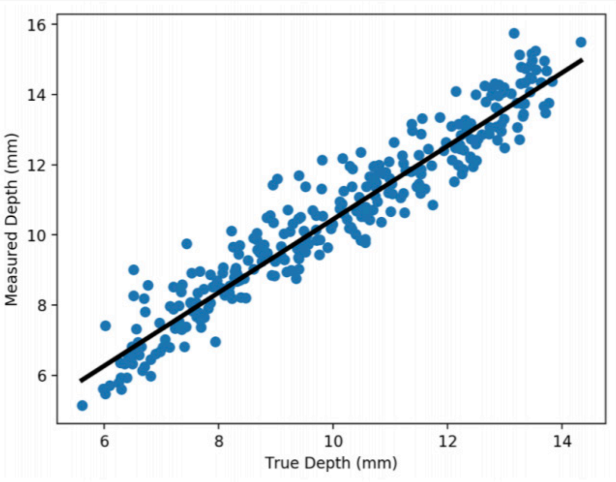

FIG. 2. The result of performing the optimisation to determine the best sensor. The measured depth from the sensor is plotted as a function of the known true depth at which that measurement was performed. A linear line of best fit is plotted to show the correlation between the two values.

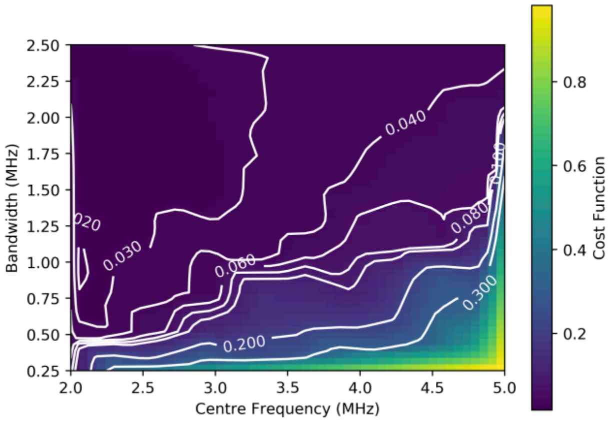

FIG. 3. The value of the optimiser cost function as a function of the two parameter considered in the optimiser, the centre frequency of the sensor and the bandwidth of the sensor. Contours of constant value are plotted in white with their numeric value in-line.

Conclusion

This work has demonstrated a methodology that allows the efficient optimisation of non-destructive inspections. This methodology is generic to any model that can be described by a set of quantitative inputs and outputs and can therefore be applied to another inspection modality or another discipline of engineering entirely. It can significantly reduce the cost and time burden of optimising an inspection, alleviating the need to produce a large number of sensors and defect specimens to inspect.

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