An Ultrasonic Guided Wave Tomography Approach for Pipeline Health Monitoring
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ABSTRACT

An ultrasonic guided wave computed tomography (CT) technique has been developed to monitor degradation in pipeline. Degradation here refers to corrosion, erosion, or fatigue cracking. A sparse guided wave sensor array can be embedded on pipeline and baseline data sets can be compared with subsequent data sets to produce CT images of damage that occurs in the structure. The resulting CT images are capable of determining damage size, location, and severity. The technique can be used to detect and discriminate between multiple damaged regions in localized areas and can be applied to, for example, straight pipeline sections, elbows, and/or welds. Several CT algorithms have been developed that take advantage of different guided wave features for image construction. Selection of the proper CT algorithm has shown the ability to increase damage detection probability and decrease false defect calls.

INTRODUCTION

Ultrasonic guided waves offer an attractive solution for nondestructive testing (NDT) and/or structural health monitoring (SHM) of pipeline and pipeline related structures. Unlike conventional bulk wave ultrasound, where a given transducer only provides information about the structural region directly beneath the transducer, guided waves interact with the boundaries of a structure to form wave packets which can travel many feet with minimal attenuation. Therefore, guided waves can be used to inspect large structural areas, or inaccessible areas underneath coatings, concrete, soil, etc. Further, low-profile, light-weight guided wave sensors can be fabricated relatively inexpensively and are suitable for embedding. The use of embedded sensors allows data to be compared over time, resulting in improved sensitivity for damage detection as subsequent data sets can be compared to a baseline data set to look for signal changes caused by damage in the structure. This phenomenon also allows for damage growth rate predictions.

Computed tomography (CT) imaging, using ultrasonic bulk wave techniques, is used extensively in medical imaging and many ultrasonic NDT applications. Most of these techniques use classic reconstruction algorithms that were developed for x-ray tomography. The work presented here concentrates on using an algorithm called Reconstruction Algorithm for Probabilistic Inspection of Damage (RAPID). The RAPID algorithm, which was first reported in [1], was developed specifically for ultrasonic guided wave applications. The algorithm constructs images based upon changes in the received signal and, therefore, requires two sets of data for image construction. Recent work efforts have shown that when using this algorithm, it is possible to accurately detect and image corrosion, pitting, and fatigue cracks in a variety of structures, including isotropic [2] and anisotropic composite plates [3], aircraft skins [4], pipeline [5,6], and other tubular structures.

TOMOGRAPHY ON PIPELINE

One example showing how the guided wave CT approach can be used to monitor the health of pipelines is presented in Figure 1. In this example, two guided wave sensor arrays are mounted around the circumference of the pipe at two different axial positions. Note, as shown, the sensors are low-profile and packaged for robustness. A reference guided wave data set was acquired by transmitting and receiving ultrasonic energy between the two sensor rings in a through transmission setup. The ultrasonic energy is transmitted and received using every possible sensor combination in the array. Damage, in the form of material removal, was then introduced and a new data set was acquired. A CT image was then constructed by comparing the reference data set with the “after damage” data set.
Similar approaches can be used to monitor localized pipe regions [5] or erosion occurring at a pipe elbow [6].

Figure 1 - Photo showing one setup for using a guided wave CT approach for pipeline health monitoring. The pipe shown here is a 10” diameter Schedule 40 steel pipe. As shown, two guided wave sensor arrays are mounted around the circumference of the pipe at two different axial positions (48” apart). Data is acquired before and after introducing damage to the pipeline to create the CT image shown in Figure 2 below.

Figure 2 - CT image for the 10” pipeline with damage described above in Figure 1. Note the damaged region is clearly depicted in the image.

TOMOGRAPHY ON SOCKET WELDS

The Electric Power Research Institute (EPRI) presented us with a problem regarding the cracking of socket welds. We approached the problem using the through transmission method implemented with two circumferential arrays of transducers. One array was placed above the socket weld and the other below the socket weld. See Figure 3.

The socket weld specimen on the right in Figure 3 was vibrated to weld failure on a shaker table at the Pacific Gas & Electric testing facility in San Ramon, California, USA. Two types of data were collected: direct through transmission, transducer to matching transducer (as shown in the Figure, 1-17, 2-18, etc. and tomographic data as shown in Figure 4.

Material removal
~1” x 2”, 0.010” deep
On bottom of pipe

Material removal
~1” x 2”, 0.010” deep
On bottom of pipe
The results of the through transmission approach are shown in Figure 5. Since the vibration was in one direction (symmetric loading), two cracks, ~ 180° apart occurred. A third crack was also initiated. [0 position on the x-distance scale]

Using the arrangement of Figure 4, in sequence around the circumference, one transducer at a time was received by 7 transducers. This sequence was followed until the entire circumference was covered. Using an in-house tomographic algorithm, the image shown in Figure 6 was generated.

Alternative form of socket weld (shown leaking)

Figure 3 - Photographs of socket welds. The socket weld test specimen on the right had two circumferential arrays mounted on it. One above the weld and one below. The arrays were used in the through transmission mode.

Figure 4 - Schematic illustration of the scanning procedure for acquiring data necessary for tomographic imaging of a socket weld. Each transducer transmits to, for example 7 receivers (considering the curvature of the pipe). If N=16, then 16*7 or, 112 paths will cross the socket weld from the assay above the weld and 112 paths from the array below the weld.
CONCLUSIONS

An ultrasonic guided wave tomographic approach has been developed and shows excellent promise for structural health monitoring. The technology uses embedded sensors to monitor structural health over time and is capable of producing images showing structural damage, size, and severity. The
integration of the technology with power harvesting and wireless data transmission will result in a fully autonomous health monitoring technology.

REFERENCES


