Corrosion and crack detection in welded plates using Lamb waves

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Objectives:

- To design and construct a portable system for corrosion and crack detection using \textit{weld guided and phased array Lamb waves}

Potential uses include:

- \textbf{Structural Health Monitoring} e.g. using permanently mounted transducers for long term corrosion detection in inaccessible regions.
  - e.g. inaccessible areas of ships.
  - e.g. welds between steel plates, in pipes, fatigue cracks etc

Engine room HMS Tyne
What are weld guided modes?

“Weld guided modes” are Lamb waves which are confined to the bead of the weld.

Weld guided modes have the advantage that they propagate many metres – but limited just to weld/HAZ.

Main limitation will be due to attenuation/reflection of signals from structural features such as stiffeners or bulkheads.

-Confinement occurs because the weld is thicker than the plate, and the phase velocity is lower than in the plate.
Synthesise an image using array of transducers

Methodology based on technique known as Full Matrix Capture to synthesis image using array.

Capture waveforms from all pairs of transducers, 1→2, 1→3, 1→4, .................. 4→5,

Post processing in software is then applied to the waveforms by dividing the target region into a discrete grid, and then summing the signals to synthesise a focus at every point in the grid,

\[ I_{tot} = \sum I(x,y) \quad \text{where} \quad I(x,y) := h_{tx,rx} \cdot \frac{1}{{c} \sqrt{\frac{x - x_t}{c}^2 + \frac{y - y_t}{c}^2 + \frac{x - x_r}{c}^2 + \frac{y - y_r}{c}^2}} \]
Design of a lap-top based SHM system: transducers

- Use rectangular transducers, and glue to surface, e.g. 25mm x10mm x1mm

Wrap around electrode

Perp (0°)
Parallel (90°)

- Transducers size and geometry chosen such that they were directional and resonant in one direction, but not in the other – this suppressed unwanted modes and unwanted edge reflections.

S0 and A0 amplitude as a function of frequency

Polar plot for rectangular 25mm x 10mm transducers – derived using optical single slit analogue
System comprised an arbitrary waveform generator, A to D converter, pre-amp, multiplexer and lap top.
Lab based results: Steel test plates used here representative of type used for ship construction

*Plate 1*: 4mm thick, 2m long 1m wide with weld along middle. This had machined defects representative of corrosion flaws, plus also numerous inherent weld flaws

Actual isolated corrosion defects.

Simulated corrosion defects.

Transducers = pink rectangles
Weld guided mode with rectangular transducers, using large plate and machined defects
Using 25 x 10mm transducers at ~200kHz, wavelength about 25mm

Results:

Looking from left end of plate with corners removed

Looking from right end of plate without corners removed

Amplitude
Distance (cms)

19mm dia, 2mm deep part thru hole
25mm dia, thru hole
Results:

**Weld guided mode**: Comparison of directionality between *rectangular* and omnidirectional *circular* transducers, large plate.

- **Rectangular** transducers:
  - Both looking from right end of plate *without* corners removed

- **Circular** transducers:
  - 19mm dia, 2mm deep part thru hole
  - 25mm dia, thru hole

So rectangular transducers made a large difference in weld hole reflection visibility
Large steel plate, array system
S0 200kHz using 4 transducer array of 25mm x 10mm
**Weld guided mode**, small plate 0.93m long

Exposed to accelerated corrosion atmosphere in a salt spray cabinet for 1000hrs, and then dried.
Results for the small steel plate using weld guided mode

In this instance corrosion was generalised along the length of the weld/HAZ and not possible to identify discrete reflections.

So instead, looked at change in amplitude/transit time (as a result of scattering) during salt spray exposure and also after drying.

Amplitude changes

Some scatter in results, but consistent decrease of amplitude during salt spray, but no consistent changes with drying.
Results on monitoring velocity changes

Transit time changes (or group velocity changes) – possible origin from surface scattering

Consistent increase in transit time with immersion, and **consistent decrease with drying**. – *So no good for monitoring*

Probably implies protective sealant influencing measurements.
Array imaging results for 3.2mm plate, 500kHz, S0 mode
Simulated corrosion defects, 5 transducer array 12.5mm x 5mm x 0.5mm

Choose S0 at ~500kHz ($\lambda \sim 10\text{mm}$)

$0$
$0.1$
$0.2$
$0.3$
$0.4$
$0.5$
$0.6$
$0.7$
$0.8$
$0.9$
$1$

Freq (kHz)

Amplitude (volts)

$S0$ perp
$A0$ perp
$S0$ parallel
$A0$ parallel

2mm dia through-hole

$\sim$4mm dia surface flaw

$\sim$4 x 6 mm surface flaw
Model side lobe generation using approximate multiple optical slit diffraction analogy

- Permits exploration of transducer length and spacing (in terms of $\lambda$) to directionality and formation of side lobes
Directionality and dispersion curve for 3.2mm plate, 12.5mm x 5mm x 1mm transducers

Use A0 at ~800kHz (\(\lambda\) ~3mm)

Potentially a good frequency to operate because good A0 and poor S0 in forward direction. Also large dispersion of S0 at 800kHz which should further reduce any overlapping unwanted modes.
5 transducer array imaging of simulated fatigue cracks under doubler plate
12.5mm x 5mm x1mm transducers

Sawcut, 7mm
3.2mm doubler plate bolted to plate
12.5x5x1mm transducers
250mm

Transducer approx 3 $\lambda$ long, separation $\sim\lambda$
Conclusions and summary

- Weld guided S0 Lamb wave mode propagation and S0/A0 phased array system suitable for either weld/HAZ and plate inspection has been demonstrated. These work even in aggressive hostile environments.

- This offers a very promising method for corrosion detection/flaw detection

- Using inexpensive, permanently attached resonant rectangular transducers of correct dimensions provided significant forward gain with suppression of unwanted modes.

- A working, relatively simple lap-top based system has also been developed which would be suitable for autonomous operation and monitoring inaccessible locations.

- So far, the method is actually quite good for flat plate like structures or welds, where there is not too much complexity – further work required to look at more complicated structures e.g. changes in thickness or doublers and presence of structural features and their contribution to coherent noise generation.