

Long Range Ultrasonic Guided Waves for Pipelines Inspection

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INTRODUCTION

In-line inspection vehicles (Smart pigs) are used today to detect corrosion, cracks and dents in a pipeline by crawling or swimming through the pipe internally. These vehicles occupy the entire internal circumference of a pipeline in order to provide 100% inspection coverage of the pipeline whilst using ultrasonic or magnetic sensors. They can cope with moderate changes in diameter and moderate bends in the pipeline but in practice there is a large variation in pipe sizes. For example, common steel pipelines used for gas/crude/oil-products have internal diameters between 150 mm to 350 mm while larger pipes have internal diameters of 500 mm to 1,380 mm. Therefore, a diameter matching pig is required for each pipe size and for the larger diameters these pigs tend to be very large.

The goal of PIGWaves project is to develop a single internal in-service pipeline inspection tool capable of inspecting both piggable and currently unpiggable oil pipelines.

PIGWaves project - "In-Line Service for Internal Inspection of Unpiggable Buried Oil Pipelines Using Long Range Ultrasound Guided Waves in Fifty Metre Segments" is a European Research & Development Project funded under FP7/Capacities "Research for SMEs" Programme. This project addresses the need to develop inspection tools for in-service Non Destructive testing (NDT) inspection of unpiggable pipelines meeting the international standards such as the ISO (13623-16708-21329) and IEC.

The use of latest technologies and new developments will allow performing total volume inspection far more rapidly and cheaply. Moreover the proposed pig by this project will enable inspection of pipelines with diameter reductions caused by obstacles or sharp bends. The technical objectives involve the development of an innovative, flexible Long Range Ultrasonic Testing (LRUT) collar adaptable to typical steel pipes used in the Oil & Gas pipelines and reduce 'false-calls' from pigging by using LRUT to assess indications.



Figure 1. Oil and Gas pipeline

Using a collar with LRUT for inspection has significant advantage over a similar collar using a more conventional, localised inspection techniques such as Ultrasonic Testing (UT) or Magnetic Flux Leakage (MFL). One major advantage is that data collection can happen every 50 metres whilst maintaining 100% coverage of the pipeline, whilst with conventional methods data collection is performed every few milli-meters. This leads to reduced data gathered and faster inspection time.

The operation of LRUT inspection consists of generating ultrasonic waves to propagate within the pipelines in order to detect metal loss and other defects due to corrosion or other degradation processes. These waves are transmitted along the pipeline by physically attaching multiple rings with ultrasonic transducers on the internal or external circumference of the pipeline. Defective areas produce reflections of the ultrasonic waves which are picked up by the transducer, making it possible to identify defects.

Theoretical modelling is key to understanding the fundamental mechanisms, but also to visualise the acoustic behaviour such as the field pattern generated in the material and to aid the interpretation of received signals. COMSOL Multiphysics® simulation software was used to study the behaviour of such guided waves in the PIGWaves project. A transient regime model allows to:

- ❖ Generate numerical FEA.
- ❖ Couple Elasto-dynamics with electro-magnetics.
- ❖ Use FFT to extract the frequency content from the A-scans.
- ❖ Use 2D FFT to identify the content of the extrusion plots (A-scans at different positions) with regards to frequency/space.
- ❖ Show how discontinuity (defect) will affect the wave propagation.
- ❖ Show the effect of the remaining thickness on the mode conversion.

Piezo-electric transducers vibrate in shear mode along the test surface unlike the transducers used in conventional ultrasonics. If the transducers are arranged to vibrate in a circumferential direction, then a torsional wave is produced.

A ring of axially orientated transducers generates an axi-symmetric longitudinal wave in both the forward and backward directions, which are also 100% reflected at the flange. This is due to the large difference in acoustic impedance between the pipe and the air. As with conventional ultrasonics, the rings fire a pulse and then rest for a period to detect reflected echoes. Echoes from symmetrical features around the pipe, for example girth welds and flanges reflect symmetrical waves back to the tool. Non-symmetrical features however, do not reflect symmetrical waves but instead reflect flexural modes.

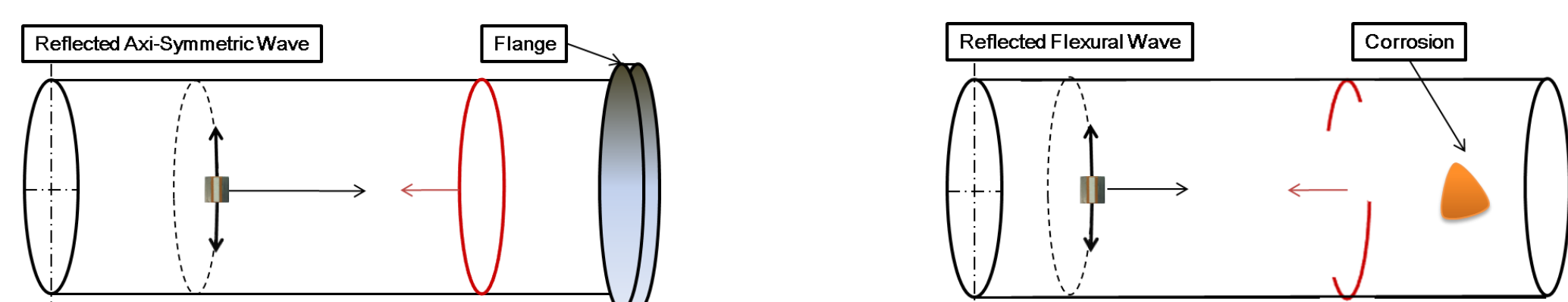


Figure 2. 20% of thickness loss

COMPUTATIONAL METHODS

Sample

Using COMSOL Multiphysics®, a 12 inch pipe Sc40 sample with the following characteristics is analysed:

- ❖ 303.22mm internal diameter (11.938")
- ❖ 10.3124mm wall thickness (0.406")
- ❖ Length 5 metres

The double array of transducers is positioned on the middle of the pipe (2.5m).

The excitation applied to the transducer is a 5 cycle (n) Hanning pulse at a frequency of 60kHz (f). The speed of propagation in the material is considered to be 3000m/s. The acquisition time is up to 1 ms in steps of 1 μs.

$$excitation = \sin(\omega t) * (1 - (\cos \omega t / n))(t < f/n)$$

The number of elements of the mesh 155904 and the number of degrees of freedom is 4219776 varying the solution time depending on the model complexity.

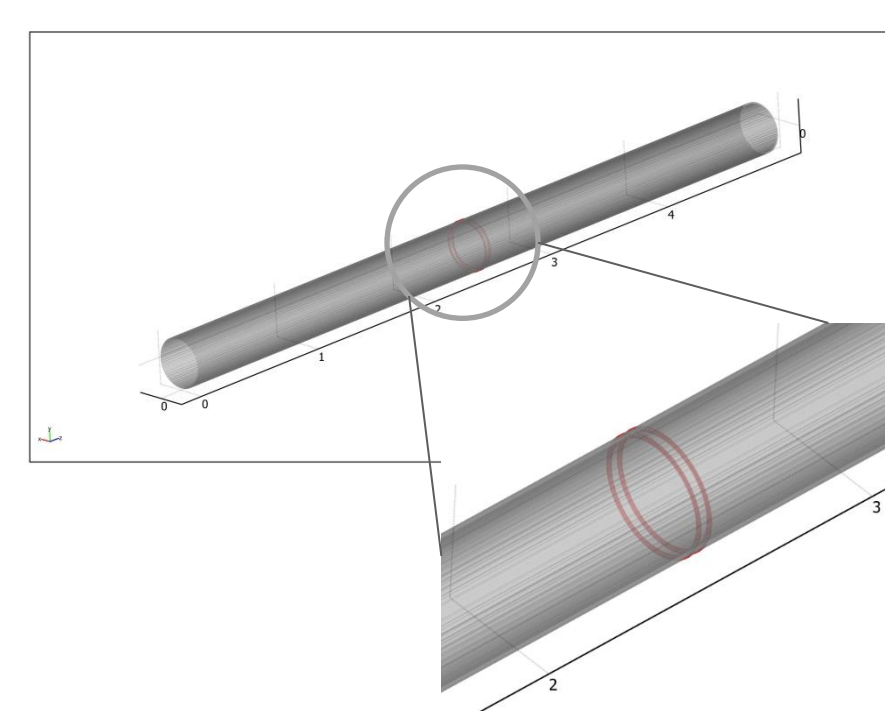


Figure 3. Test sample. Transducer array

Defect simulation

A simulated defect is introduced on the model. Different thickness losses have showed different signal results. The distance from the array of transducers to the defect is 1.5.

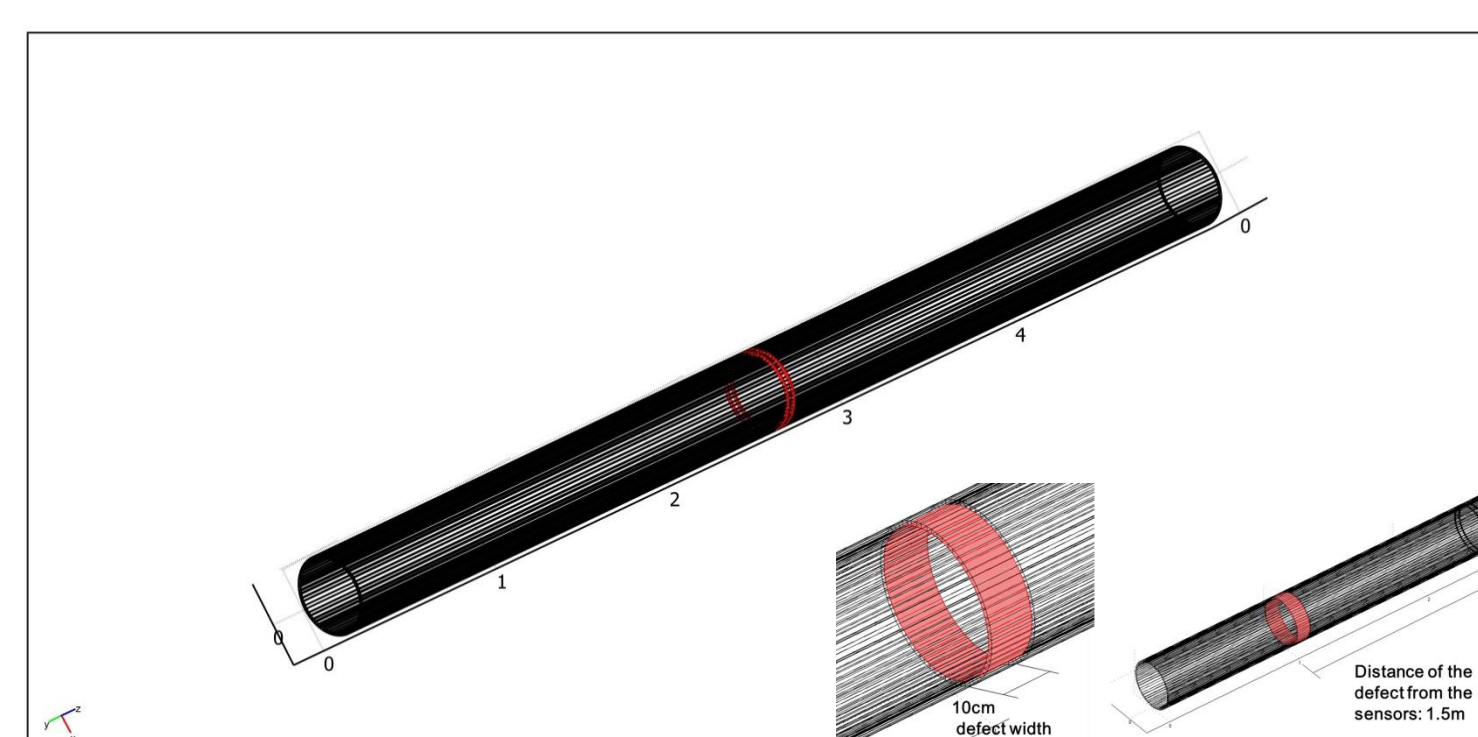


Figure 4. Defect simulation

Figure 4 shows how the defect has been included on the model.

By introducing a defect, changes in the received signal amplitudes can be analysed. The first simulated thickness loss is 10% of cross sectional area (CSA). This is made as the reliable detection target.

RESULTS

In order to analyse the results, behaviour of Guided Waves (GW) have to be understood.

- ❖ GW transmitted at the sensor location on the inner surface of the pipe.
- ❖ GW travels in both directions until it reaches the end of the pipe.
- ❖ GW reflects and reflected echoes are sent back to the sensors.

Rings cancellation principle

Having Guided Waves propagate in both the forward and backward directions simultaneously creates a problem for analysis since the time domain signal will contain echo-signals from both directions and it will not be possible to differentiate between them. By having two rings of transducers and sensing the sequence in which the reflected wave passes the two rings, it is possible to differentiate waves from the forward direction to the backward direction.

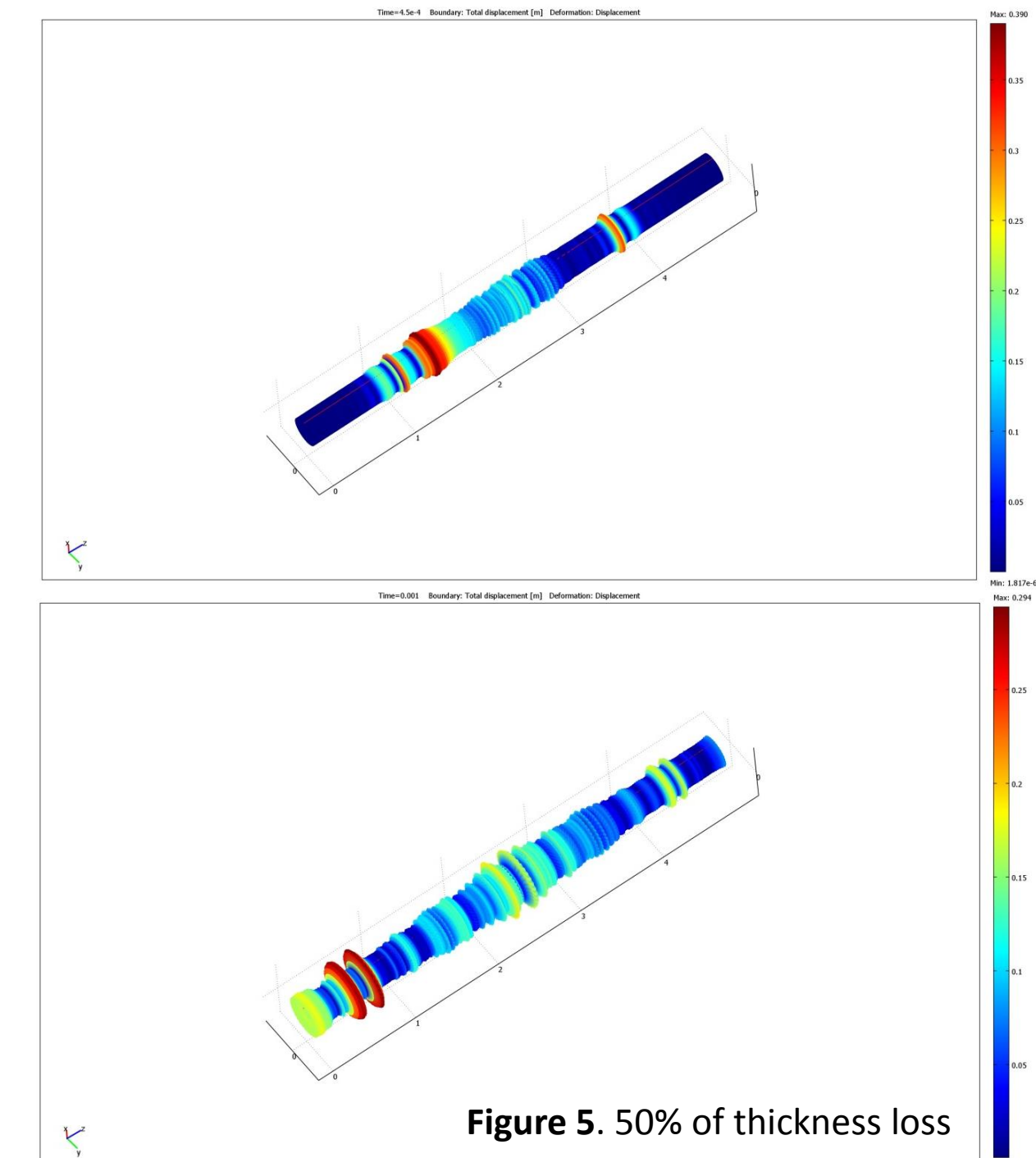


Figure 5. 50% of thickness loss

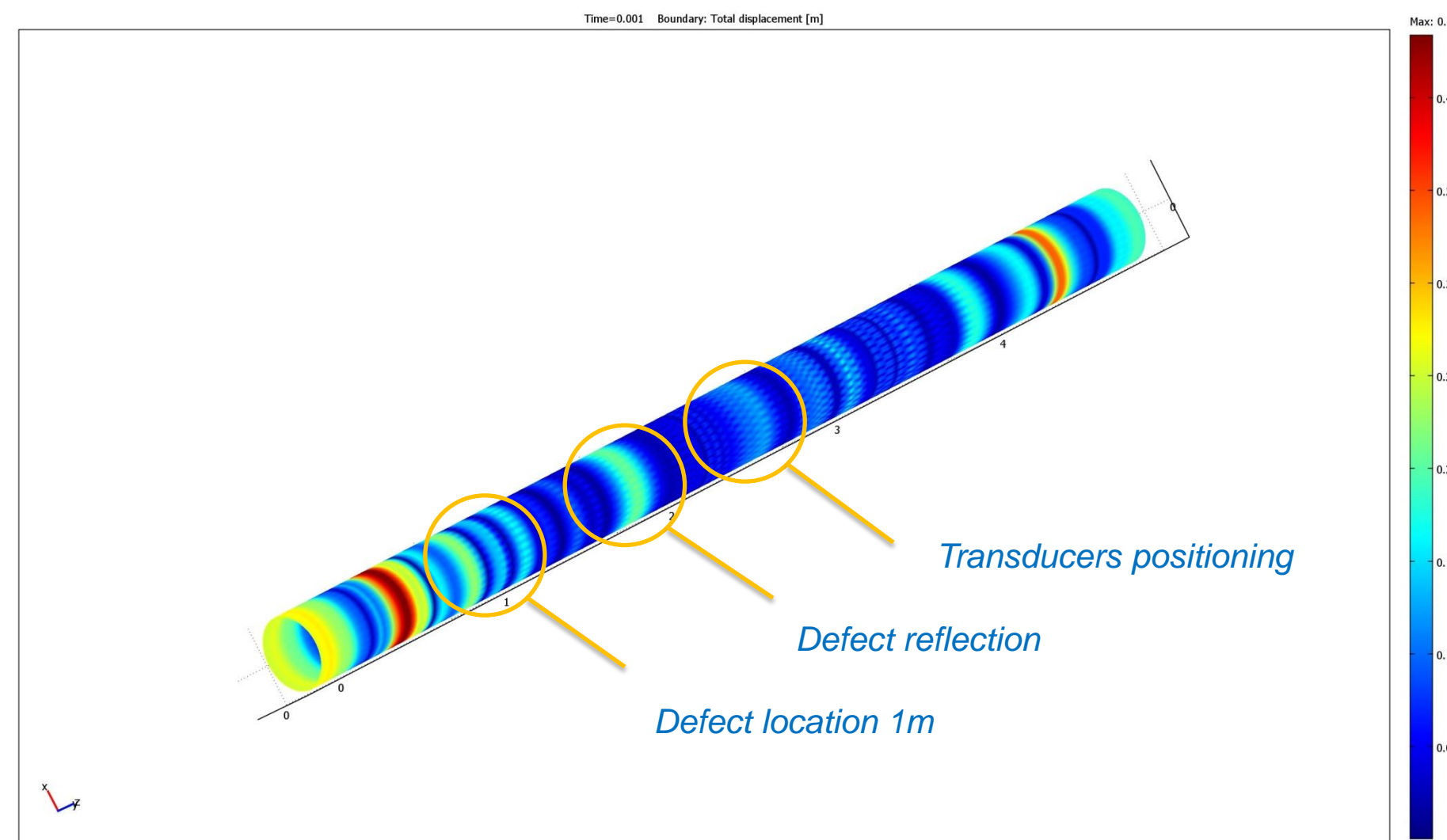


Figure 6. 50% of thickness loss

Defect Characterisation

Evaluating the size and the nature of the defect are two of the most controversial topics in ultrasonic defect detection. Defect sizing in particular can be a complex subject, with various defect characterisation techniques being advocated or condemned by many experts in the field. The simulation is used to interpret and process the obtained signals.

Extrusion plots represent a cross-sectional profile of the Guided Waves propagation along the pipe. The displacement is shown in relation with time. Figure 7 shows a cross-sectional profile of the wave propagation along the pipe by introducing a simulated defect of 20% of wall thickness loss. The defect was placed at 1m from the pipe end.

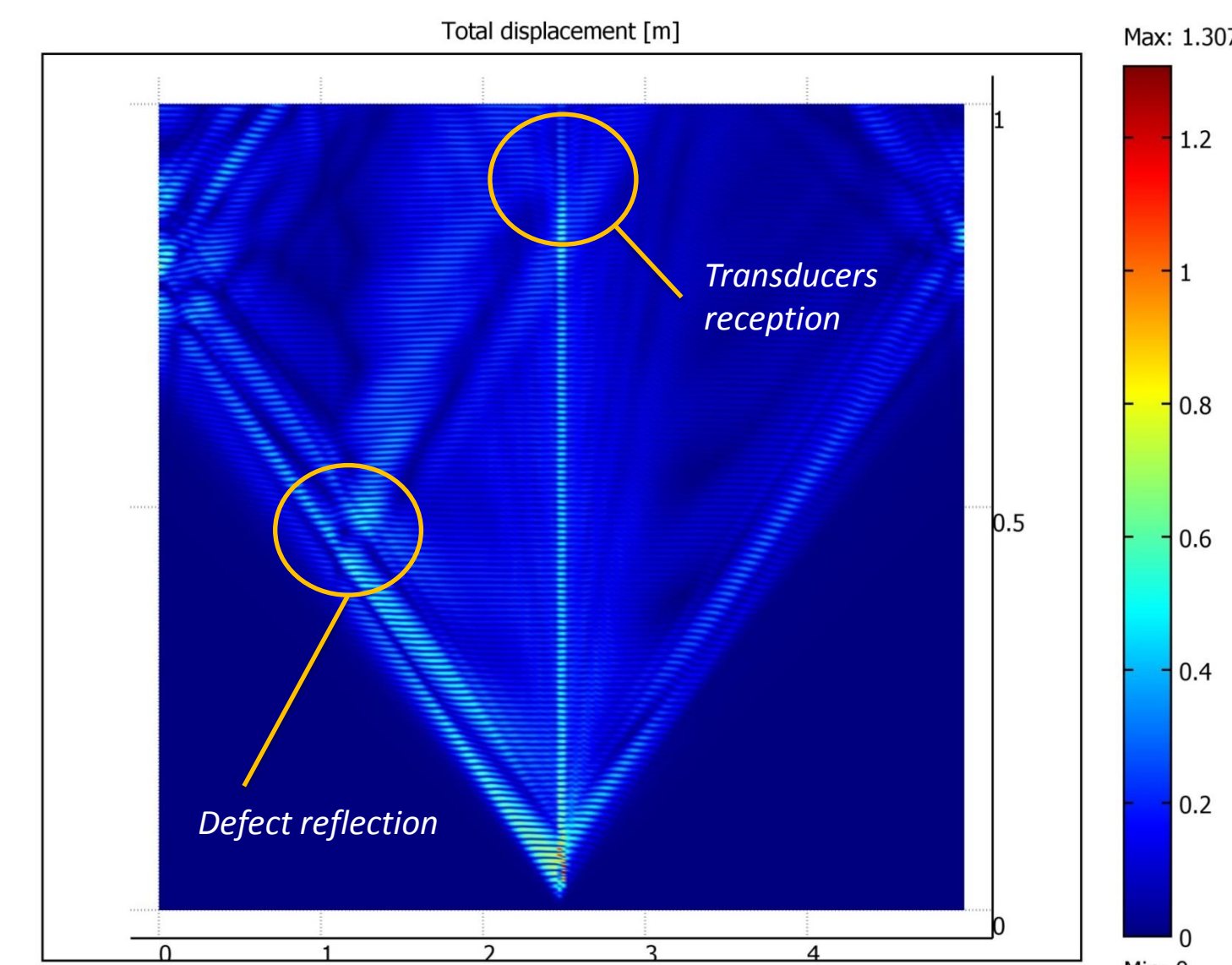


Figure 7. 20% of thickness loss

The horizontal axis represents the distance from the transducers to the end of the pipe in metres and the vertical axis represents the time in milliseconds. The colour scale represents the energy of the Guided Waves (total Guided Wave amplitude).

Simulated scenarios show a reflection at the end of the pipe. As it can be observed in Figure 7, part of the energy is reflected from the defect located 1m from the pipe end. This energy will be received by the transducers at a shorter period of time than the pipe end reflection. This fact will determine the defect position using the time of arrival and the wave speed.

As for conventional ultrasonic testing, signal amplitude can be a mean of defect sizing. Figure 8 shows several A-Scans of different scenarios of wall thickness loss. The non-defected model (0% thickness loss) and models with 20%, 35% and 50% wall thickness loss present significant differences in terms of wave amplitude. The time of arrival indicates the position of the defect. The amplitude can provide information about the material loss estimation and its severity, classifying the defect in different categories.

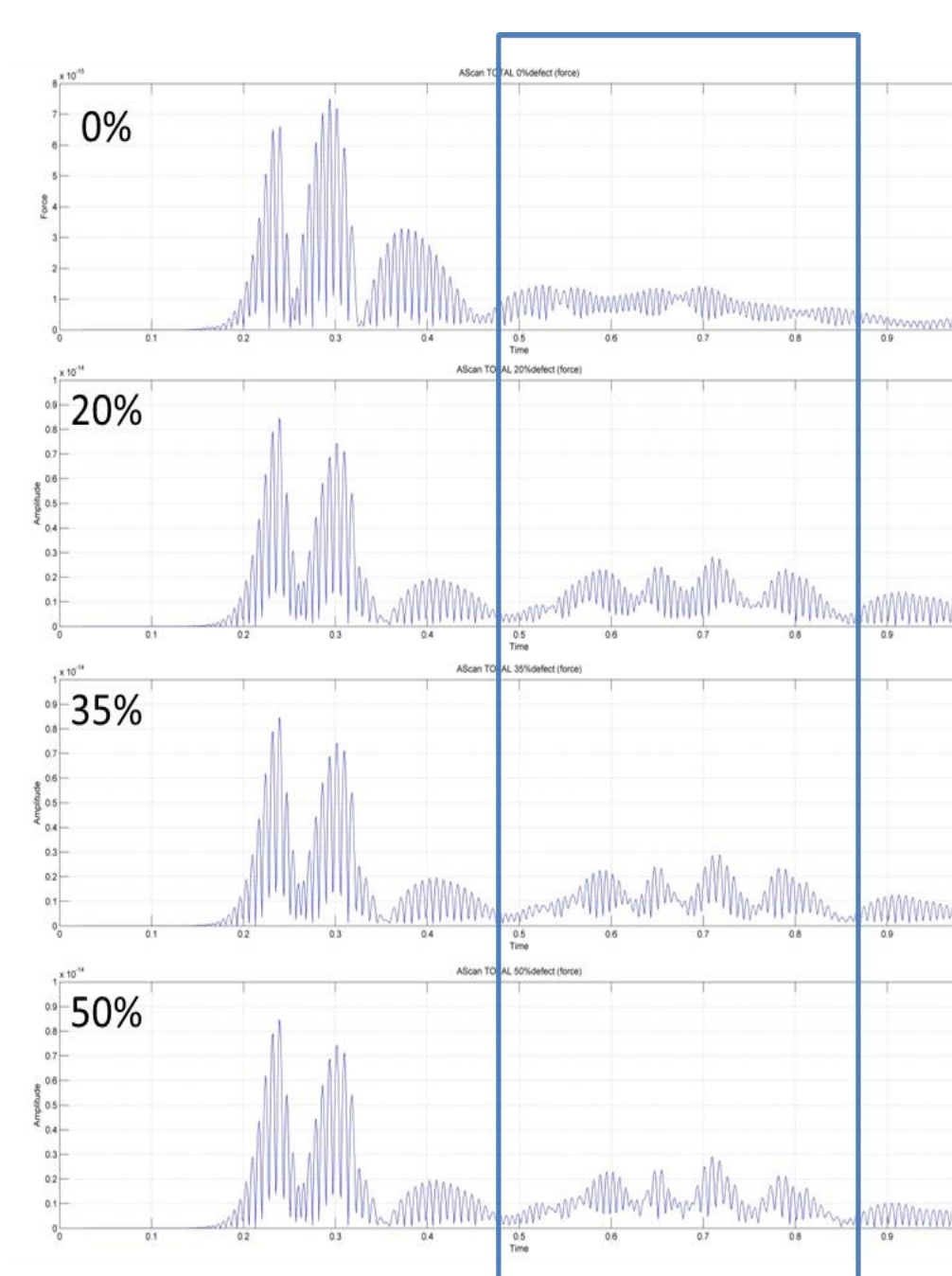


Figure 8. A-Scans at 1.75m from transducers. 0, 20, 35 and 50% of wall thickness loss

Probability of Detection (POD)

The probability of detecting a defect is defined by the error function assuming that Gaussian statistics apply i.e.

$$POD = \text{erf}(V/V_{noise})$$

V is the voltage amplitude

A specific evaluation of the POD based on the results obtained for the 50% defect size with respect to the defect free model is given in Table 1.

	Max V	Max V _{noise}	Ratio	POD
Best case	2.9	1.5	1.93	99%
Worst case	2.2	1.5	1.46	80%

Table 1. Probability of detection

As expected, for a defect representative of 50% wall thickness loss, the POD in ideal environmental conditions is very high. Under practical conditions the POD is a more complex function that used additional parameters such as:

$$POD(l, q) = 1 - e^{-q/l^\lambda}$$

l is the defect size.
λ is the expected value of smallest detectable damage
q is the quality factor.

CONCLUSIONS

Feature classification is based on signal amplitude and recommendation for follow up priority from the screening operation can be obtained. The outcome of this interpretation is a decision as to whether the follow up inspection is of High, Medium or Low priority. The degree of defect severity needs to be assessed, and this is done by looking at the signal amplitude for a specific level of metal loss.

A deep study is required to characterise the defects. Large amplitude responses will be from a large cross-sectional area defect. Small defects cannot produce large amplitude reflections.

10% of thickness loss of cross sectional area (CSA) is the lowest reliable detection threshold that can be assured. Smaller levels of metal loss have been detected using this technique; however a lower target level can result in an increase in false calls.

CONTACT INFORMATION

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