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PII: S0963-8695(17)30296-7
DOI: 10.1016/j.ndteint.2017.09.007
Reference: JNDT 1913

To appear in: NDT and E International

Received Date: 24 May 2017
Revised Date: 16 August 2017
Accepted Date: 21 September 2017

Please cite this article as: Heinlein S, Cawley P, Vogt TK, Reflection of torsional T(0,1) guided waves from defects in pipe bends, NDT and E International (2017), doi: 10.1016/j.ndteint.2017.09.007.

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Reflection of torsional T(0,1) Guided Waves from Defects in Pipe Bends

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Keywords: Guided Waves, Pipe Bends, Torsional Waves

ABSTRACT

This paper investigates the reflection of the torsional T(0,1) mode from defects in pipe bends. The effect of varying circumferential and angular position along the pipe bend, as well as the influence of the bend radius, is investigated via 3D finite element simulations. The results show that the reflection expected from a small defect varies significantly with position, the minimum reflection coefficient being about 10\% of that from a comparable defect in a straight pipe, while maxima of around four times the straight pipe value are seen. The areas of low detectability are mainly found on the bend intrados and those of high detectability close to its extrados; similar effects are seen in bends with radii varying from one to twenty pipe diameters. It is shown that the reflection from a defect at a given location is roughly proportional to the square of the von Mises stress produced by the transmitted wave at that position. This holds for defects such as circumferential cracks, the detailed subject of this investigation, and is also expected to be valid for corrosion patches; it will not hold for axial cracks. The results explain the low reflection seen from a simulated corrosion defect at a bend in a previous investigation.

1. Introduction

Guided wave inspection has been in use commercially for over a decade for the detection of corrosion and other defects in pipework in a range of industries including oil and gas\cite{1}\cite{2}. In the most common implementation, a non-dispersive torsional T(0,1) signal is introduced into a pipe using a ring of piezoelectric transducers \cite{3}; alternatively a system with magnetostrictive transducers can be used \cite{4}\cite{5}. The walls of the pipe act as a one dimensional waveguide, allowing the signal to travel tens of meters in each direction from the measurement location \cite{3}. Unlike traditional ultrasonic inspections this enables the measurement to cover large volumes of pipework from a single inspection position. Defects, such as corrosion or cracks, will cause a part of the input wave pulse to be reflected; the amplitude of this reflected signal increases with the cross sectional area loss of the pipe caused by the defect \cite{6}\cite{7}. The defect signal is recorded by the same transducer ring as used for transmission, allowing for the location of the defect to be determined using the travel time of the wave pulse. During a conventional guided wave inspection the time trace recorded by the transducer ring will be evaluated manually by the operator. The minimum defect size to be found with this methodology in practical applications corresponds to approximately 5\% cross sectional area loss of the pipe wall \cite{8}. This value can vary significantly depending on the position of the defect, the general condition of the inspected pipe and the presence of other pipe features \cite{9}.
Pipe bends pose further difficulties as they introduce mode conversion such that signals from beyond bend are more complex thus making interpretation more challenging, thereby reducing detection sensitivity [10].

There is an increasing interest in permanently installed guided wave structural health monitoring (SHM) systems [11]; these have been in use commercially in pipe monitoring applications [12]. A blind trial of such a system (gPIMS produced by Guided Ultrasonics Ltd) was conducted by ESR technology [13]. The monitoring was performed on an 8 inch diameter schedule 40 carbon steel pipe containing a 90° 1.5D bend section as seen in Fig. 1 (a). A number of defects were introduced into the setup and incrementally increased in size such that the sensitivity and validity of the new SHM method could be investigated. A total of five defects in the straight pipe sections before as well as past the bend could be identified. These defects were first detected at a cross sectional area loss of between approximately 0.5 and 1.5%. A sixth defect, unlike the rest, was placed on the pipe bend roughly at the 12 o’clock position i.e. on top of the bend. An image of this defect can be seen in Fig. 1 (b). It was only possible to identify this defect after it had been grown to a cross sectional area loss of 3.5% i.e. substantially more severe than the other defects. Even after the conclusion of this trial with the knowledge of the defect size and position it was not possible to identify the defect retrospectively from earlier measurements. This suggested that the reduced detectability of the bend defect is not related to a shortcoming of the SHM methodology but rather limited by the geometry of the pipe setup and the particular location of the defect.

In an initial finite element investigation, the reflections from a number of through thickness slits of different circumferential extent located at the 12 o’clock position and an angular position of $\theta = 45^\circ$ along a 1.5D bend were compared to those obtained from defects of the same size positioned in a straight pipe section. It was found that the amplitude of the reflections from the defects located on the bend was reduced to 30-40% of that from defects on the straight pipe; these values correspond with the results obtained in the blind trial [13]. This suggested that a more comprehensive study of the influence of defect position in a bend on the reflection obtained would be valuable.

![Fig. 1. (a) Setup of the 8 inch pipe with a 1.5D bend section used in the blind trial [13]. The transducer ring is shown in green. Defects are highlighted in grey. (b) Example defect located on the pipe bend at the 12 o’clock position.](image)

There has been little work published on the reflection from defects in pipe bends and on the influence of the precise position of the defect in the bend. The propagation of the $L(0,2)$ mode [14] as well as its reflection from defects at various positions on pipe bends has been investigated more than the $T(0,1)$ mode [15][16]. It was found that the reflection from a crack at the bend intrados was significantly lower than that from a crack
of the same size at the extrados of the bend. Qi et al. [17] studied T(0,1) mode reflections from axial defects at three different locations on a pipe bend, observing varying detectability with position. Jack et al. investigated the reflections of L(0,2) and T(0,1) waves from circumferential defects at bend welds. Rose et al. [18] used flexural mode tuning to improve the detectability of defects on a pipe bend and investigated the reflection from defects located past the bend [19], while the scattering of the T(0,1) mode from junctions of straight pipe sections and bends was investigated by El Bakkali et al. [20]. The nature of modes in a bend [21][22][23] and mode conversion of guided waves traveling through bends have been studied extensively in the past decade using experimental as well as finite element approaches [24][25][10][26][27]. To the authors knowledge there has not been a systematic study of the sensitivity to defects as a function of their position along and around a pipe bend for the T(0,1) incident mode.

This paper studies the spatial variations in the sensitivity of guided wave inspections as a function of defect position around a bend and as a function of the bend radius. The original motivation was to find an explanation for the results of the blind trial [13], but it will also be a valuable tool in understanding the ability of guided wave inspections to detect defects on pipe bends. To obtain a sensitivity map of a 1D pipe bend the torsional T(0,1) wave reflections from small defects located on the bend with varying circumferential and angular position were studied. The results were obtained from a numerical finite element model of a pipe section similar to that employed in the blind trial as shown in Fig. 1.

Section 2 specifies the properties of the finite element bend models used. This is followed by a description of the defects introduced into the model and the stress and displacement outputs generated by the analysis. In section 3 the results from the crack study are presented and compared to the stress distribution in a bend of the same size. The correlation between the two is discussed and the stress distributions in 2D, 3D, 5D, 7D and 20D bends are presented. Next, in section 3, the expected reflections from defects at specific areas of interest in bends of different radii are compared and discussed. Section 4 presents the conclusions of the investigation.

2. Methodology

A 3D Finite Element (FE) model was constructed to investigate the behaviour of a torsional ultrasonic guided wave propagating through a bend and reflecting from defects located on the pipe bend. The mesh was generated using Abaqus CAE [28] and subsequently solved with Abaqus Explicit. Defects, source nodes as well as monitoring nodes and elements were introduced via a MATLAB [29] code; post processing of the model was also carried out in MATLAB.
Fig. 2. (a) Schematic of a 90° pipe bend. The radius of the pipe is denoted by \( r \) and the radius of the bend is denoted by \( R \). Shown in green are the locations of monitoring elements. A ring of monitoring nodes is denoted in red. Source nodes are highlighted in purple. (b) View of the meshed bend consisting of 4 elements through the wall thickness and 300 around the circumference. Element numbers in the axial direction vary with bend radius \( R \). (c) View of the bend geometry. The circumferential position is given by the value \( \phi \) with 0° at the intrados and 180° at the extrados. The angular position is denoted by \( \theta \) with 0° at the beginning of the bend and 90° at its end.

For the investigation of the problem encountered in the blind trial as presented in section 1 a model of an 8 inch diameter schedule 40 carbon steel pipe (wall thickness 8.2\,mm, inner radius 101.4\,mm and outer radius 109.5\,mm) containing a 90° bend section was created. The model consisted of 3 distinct components; firstly a 2 meter long straight section into which the input signal would later be introduced, secondly a 90° bend was connected to the previous section with a bend radius of either 1, 2, 3, 5, 7 or 20 times the outer diameter of the pipe and finally a further 1 meter length of straight pipe. The simplified geometry of the setup can be seen in Fig. 2. Shown here is a 1D bend with a radius of \( R = 0.2191\,m \).

The geometry was meshed with 300 8-node linear brick elements (C3D8R) around the circumference of the pipe and 4 elements through its thickness. The number of elements in axial direction of the bend is dependent on the bends radius. A ring of 1500 source nodes was located at the beginning of the first straight pipe section i.e. at a distance of 2 meters from the start of the bend. The excitation signal was a 2 cycle Hanning windowed tone burst, with a centre frequency of \( 25.5\,kHz \). The signal was applied as circumferential displacements of the same amplitude to all source nodes around the pipe, therefore exciting a pure torsional T(0,1) mode since the excitation frequency was well below the T(0,2) mode cut off frequency. The model was set to a total run time of 2ms allowing the signal to propagate throughout the full length of the bend.

The position of elements on the bend are denoted as seen in Fig. 3. The intrados of the bend lies at \( \phi = 0^\circ, 360^\circ \), while the extrados of the pipe is at with \( \phi = 180^\circ \). The top and bottom of the pipe are located at the circumferential position of \( \phi = 90^\circ \) and \( \phi = 270^\circ \), respectively.

In order to investigate the relative reflection amplitudes from defects located at different positions on the bend, circumferential through thickness cracks were introduced in the finite element model by disconnecting a small number of nodes. The cracks had a circumferential extent of 7.2°, equivalent to a pipe wall cross sectional area loss of 2%. The crack position was varied in the circumferential direction in intervals of \( \phi = 5^\circ \) and in the angular direction in \( \theta = 2.25^\circ \) intervals. This resulted in a total of 1400 individual FE models to be solved. Signals reflected from these cracks
were recorded by a ring of 300 monitor nodes located on the straight pipe section at a distance of 0.25 meters in front of the bend as seen in Fig. 2. The displacement amplitude and the direction of the displacement recorded at the monitoring nodes enabled the extraction of the T(0,1) mode from the reflected signals using the procedure described by Lowe et al. [30]. Flexural modes contained in the reflected defect signals were not considered during the analysis presented in this paper. The presence of the flexural modes can be attributed to the mode conversion of both the bend itself and the reflection from a part-circumferential crack. A baseline signal in the absence of defects was also collected. The baseline signal was subtracted from all subsequent measurements in order to remove any small reflections from the bend geometry itself since these are not related to the defects. The maximum amplitude of the reflected T(0,1) mode was plotted against the circumferential and angular position of the defect centre. In order to explain the resulting map of the bend the von Mises stress distribution was investigated.

Stresses and displacements were monitored in each element on the surface of the bend section between \(0 \leq \phi < 180\), halving the number of monitoring points due to the symmetry of the setup along the plane of the bend.

The Cauchy stress tensor \(\sigma\) [31] was obtained from the solved finite element model. The FE model and therefore the output Cauchy tensor are based in a Cartesian coordinate system and have to be rotated in the plane of the bend such that one dimension of the tensor can always be given as the axial direction of the pipe. To perform this operation the tensor has to be rotated individually at every monitoring element and for each time instant of the FE model. Thus the rotated Cauchy stress tensor \(\sigma'\) is obtained via the equation

\[
\sigma' = A\sigma A^T = \begin{bmatrix}
\sigma_{xx}' & \sigma_{xy}' & \sigma_{xz}' \\
\sigma_{yx}' & \sigma_{yy}' & \sigma_{yz}' \\
\sigma_{zx}' & \sigma_{zy}' & \sigma_{zz}'
\end{bmatrix}
\]

where \(\sigma\) is the Cauchy stress Tensor given by its components

\[
\sigma = \begin{bmatrix}
\sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\
\sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\
\sigma_{zx} & \sigma_{zy} & \sigma_{zz}
\end{bmatrix}
\]

and \(A\) is a 3 dimensional rotation matrix about the z axis i.e. the axis perpendicular to the plane of the bend

\[
A = \begin{bmatrix}
\cos \theta & -\sin \theta & 0 \\
\sin \theta & \cos \theta & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

with the angular position of the element at \(\theta\) as shown in Fig. 2. The angle \(\theta\) can easily be calculated from the known coordinates of the monitoring elements and the rotation centre of the bend using the equation

\[
\theta = \arccos \left( \frac{\begin{bmatrix} E_1 & R_1 \\ R_2 & 0 \end{bmatrix} - \begin{bmatrix} E_2 & R_1 \\ R_2 & 0 \end{bmatrix}}{\begin{bmatrix} E_1 & R_1 \\ R_2 & 0 \end{bmatrix} - \begin{bmatrix} E_1 & R_1 \\ R_2 & 0 \end{bmatrix}} \right)
\]
where $E = \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$ is the position vector of a monitoring element and $R = \begin{bmatrix} R_1 \\ R_2 \\ R_3 \end{bmatrix}$ is the position vector of the rotation centre of the bend. $\theta$ has a range of $0^\circ$ for the beginning of the bend to the maximum value of $90^\circ$ at the end of the bend.

The normal stress on a plane perpendicular to the pipe axis at each bend element of the FE model is given by $\sigma_{yy}$ in the rotated Cauchy stress tensor. In order to obtain a single stress value at each of the monitoring elements the von Mises stress $\sigma_v$ is calculated from $\sigma'$ using the equation [32]

$$
\sigma_v = \sqrt{\frac{1}{2}\left[ (\sigma'_{xx} - \sigma'_{yy})^2 + (\sigma'_{yy} - \sigma'_{zz})^2 + (\sigma'_{zz} - \sigma'_{xx})^2 + 6(\sigma'_{xy}^2 + \sigma'_{yz}^2 + \sigma'_{zx}^2) \right]}
$$

(5)

For the detectability of reflections from defects the stresses across the surface of the crack have to be considered. In the case of a circumferential defect these stresses are the direct and shear stresses in the axial direction. The distributions of these stresses across a 1D bend are shown in figure 4. Equation (5) can be rewritten in a cylindrical coordinate system with the circumferential and radial directions denoted by the subscripts $\phi$ and $r$ respectively:

$$
\sigma_v = \sqrt{\frac{1}{2}\left[ (\sigma_{\phi \phi} - \sigma_{yy})^2 + (\sigma_{yy} - \sigma_{rr})^2 + (\sigma_{rr} - \sigma_{\phi \phi})^2 + 6(\sigma_{\phi y}^2 + \sigma_{y r}^2 + \sigma_{\phi r}^2) \right]}
$$

(6)

The squared maximum von Mises stress as observed in each monitoring element individually is thus plotted against its circumferential and angular position.

3. Results and Discussion

Fig. 3 shows the maximum amplitude of the torsional T(0,1) mode reflected from circumferential through thickness cracks along a 1D bend. The reflection amplitudes are plotted against the circumferential and angular position of the centre of the crack. The plot was normalised to the amplitude of the reflections from cracks located at the beginning of the bend section i.e. with an angular position of $\theta = 0^\circ$. Therefore the amplitude scale is relative to the reflection expected from a $7.2^\circ$ crack located on a straight pipe. It can be seen in Fig. 3 that the reflection amplitude is at a maximum for a crack located at a circumferential positions of $\phi = 165^\circ$ and $\phi = 195^\circ$ with an angular position of $\theta = 67.5^\circ$. A local minimum can be observed at the angular position of $\theta = 60.75^\circ$ on the extrados of the pipe bend. The amplitude here is reduced by a factor of about 9.5 compared to the maximum reflection in the bend and 55% lower than a reflection from a crack of the same size in a straight pipe. The absolute minimum reflection in a 1D bend can be observed to originate from the defect located at the intrados of the pipe with an angular position of $\theta = 90^\circ$. 
Fig. 3. Reflection amplitude from 7.2° through thickness circumferential cracks plotted against the circumferential and angular position of the defect centre. Results obtained from a 1D bend of an 8 inch pipe and normalised to the reflection from a defect of the same size in a straight pipe section.

The distribution of the normal and shear stress in a 1D pipe bend can be seen in Fig. 4. For both plots (a) and (b) the amplitude of the stresses was normalised to the shear stress value at the beginning of the bend i.e. 0° in angular position. This corresponds to the stresses in a straight pipe section generated by the incident torsional T(0,1) mode. There are no normal stresses present in the axial direction of the pipe at the beginning of the bend since the only wave propagating here is the pure T(0,1) mode. The amplitude of the normal stress increases due to mode conversion with the wave passing through the bend. The highest normal stresses can be found at the 8 and 10 o’clock position of the pipe at an angular position of θ = 65°, close to the extrados of the pipe. It should be noted though that the normal stress is zero on both the extrados and the intrados over the full length of the pipe bend. The shear stress in the pipe remains fairly uniform around its circumference at the beginning of the bend as expected from the T(0,1) input signal. Mode conversion along the bend causes a reduction in uniformity of the shear stress around the pipe circumference and a maximum stress concentration can be found on the extrados of the pipe at an angular position of θ = 80°. A local minimum in the shear stress distribution can be observed on the extrados of the pipe at an angular position of θ = 60°. Comparing the distribution of the normal and shear stresses with the map of the bend obtained from the crack study (Fig. 3) a clear agreement in the location of distinct features can be observed. The positions of the two maxima in Fig. 3 match the two lobes seen in the distribution of the normal stress Fig. 4 (a). Similarly the maximum observed on the extrados of the bend in the crack study at θ = 78.75° is also found in the shear stress map of the bend as well as the local minimum on the extrados.
Fig. 4. (a) Distribution of normal stress in axial direction plotted against circumferential and angular position along a 1D bend. (b) Shear stress distribution plotted against circumferential and angular position along a 1D bend. Both plots (a) and (b) normalised to the shear stress in a straight pipe.

It was observed that the shear as well as normal stress distribution along a 1D bend both show similarities in features with the circumferential crack study. It would therefore be convenient for further study to combine these into a single value so the distribution of the von Mises stress was investigated. The maximum of the squared von Mises stress $\sigma^2_{\text{Mises}}$, calculated as described in Section 2, is plotted against the angular and circumferential position of the monitoring elements in Fig. 5. The square of the von Mises stress was used since reciprocity analysis [33] shows that the reflection from a defect is proportional to the product of stress and displacement, and displacement is also proportional to stress. Two maxima can clearly be identified at the 8 and 10 o’clock position with an angular position of $\theta = 65^\circ$. A significant local minimum is located on the pipe extrados at an angular position of $\theta = 60^\circ$. Areas of low stress can be found within the final parts of the bend on its intrados. There is a strong correlation between the crack reflection map seen in Fig. 3 and the von Mises stress map of Fig. 5, suggesting that the von Mises stress distribution is a satisfactory measure of relative reflections from cracks at different locations around a bend. It should be stressed though that this only applies to circumferential cracks which produce reflections due to both shear and normal stresses; axial cracks would not cause reflections from the normal stresses and therefore the correlation would break down. Corrosion defects produce reflections due to shear as well as the normal stresses and so the relative sensitivity to corrosion at different locations is likely to follow that of circumferential cracks presented here. As the crack study was extremely time intensive, for further bends with different radii only the von Mises stress distribution was investigated. Fig. 5 also expands the investigation of the stress past the bend for another 0.7m. It can be seen here that the stress pattern observed on the 1D bend continues in the straight section but no maxima of equivalent amplitude compared to those on the bend could be observed. The wave past the bend is therefore much more uniform around the circumference of the pipe and no strong minima are present, suggesting that beyond the bend, defect detectability will not be a strong function of circumferential position.
Fig. 5. Maximum squared von Mises stress $\sigma^2$ in a 1D bend section plotted against the angular and circumferential position of the monitoring elements. Von Mises stress also plotted for the first 0.7 m past the bend. Amplitude normalised to the stress in a straight pipe section before the bend.

The von Mises stress distributions along bends with varying radii are plotted in Figs. 6 (a)-(d). As before all amplitudes of the von Mises stress were normalised to the stress at the beginning of the pipe bend, corresponding to the pure shear stresses generated by the incident torsional T(0,1) mode. Figs. 6 (a)-(d) and Fig. 5 were all plotted on the same amplitude scale in order to simplify the comparison of expected crack reflections between bends of different radii. In Fig. 6 (a) it can be seen that the von Mises stress in a 2D bend shows similar maxima close to the pipe extrados as observed before in the 1D bend result in Fig. 5. These two lobes disappear with increasing bend radius and the maximum reflection is located on the extrados for bends with radii of 3D Fig. 6 (b), 5D Fig. 6 (c), 7D Fig. 6 (d) and 20D Fig. 6 (e). The strong local minimum found on the extrados of a 1D bend cannot be observed for any of the larger radii bends. Fig. 6 (c) also shows the von Mises stress for 0.7 m past the 5D bend. The stress distribution here shows a higher degree uniformity around the circumference of the pipe compared to the stresses past a 1D bend as previously seen in Fig. 5.
Fig. 6. Maximum squared von Mises stress $\sigma_{\text{vM}}^2$ in a bend section plotted against the angular and circumferential position of the monitoring elements. Radii of bends plotted are (a) 2D, (b) 3D, (c) 5D, (d) 7D and (e) 20D. For the 5D bend (c) the stress distribution for the first 0.7 past the bend is also shown.

Fig. 7 allows for a more direct comparison of the results obtained from the von Mises stress studies of the different bend radii. Plotted here in blue are the maxima of the von Mises stress observed on each bend. The highest von Mises stress could be observed on a 1D bend suggesting a defect at this location would yield the largest reflected signal. The maximum von Mises stresses $\sigma_{\text{vM}}^2$ for the investigated bend radii are found to be 3.0 to 4.1 times higher compared to the stresses in a straight pipe section. The minimum values of the von Mises stresses found in any element along the length of the bends are plotted in red. For each of the investigated bend radii the lowest von Mises stress could be found at the intrados. Therefore the reflection from a circumferential crack at these minimum locations would be expected to yield a relative amplitude compared to a crack in a straight pipe of 27% for a 1D bend and approximately 10% for the bends with larger radii. Finally the minimum von Mises stresses found along the extrados of the bends are plotted in green. Corrosion and erosion patches are particularly likely to form at the extrados of a bend where, in the worst case, the reflection amplitude is expected to be 60-90% for a 2D, 3D, 5D, 7D and 20D bend and 50% for a 1D bend relative to a straight pipe. For each minimum and maximum location obtained from the von Mises stress studies (Fig 5 and Fig. 6) a FE model was used to determine the reflected amplitude of the T(0,1) mode from a circumferential through thickness crack. The size of the defects and the setup of the FE model was the same as used for the 1D bend crack study in Fig. 3. The resulting relative amplitudes are plotted as crosses in Fig. 7; there is generally good agreement between the predictions from the square von Mises stress $\sigma_{\text{vM}}^2$ and the crack reflections. Fig. 7 shows
that an increase in the radius of the bend does not remove the strong variations in defect reflection amplitudes. These variations are probably caused by interference of the two wave modes propagating in the bend produced by an incoming torsional T(0,1) wave [10]. This phenomenon of natural focusing in pipe bends has been studied extensively by Rose et al.[19].

Fig. 7. Comparison of the maximum squared von Mises stress $\sigma^2_{\text{M}}$, the minimum von Mises stress and the minimum von Mises stress found on the bend extrados plotted against the bend radius. Stresses normalised to the values at start of the bend. Crosses plot the reflection of the T(0,1) mode from cracks in the corresponding locations normalised to the same defect in a straight pipe.

4. Conclusions

It was shown with a series of finite element models that the amplitude of the reflections of torsional guided waves from circumferential defects on a pipe bend are highly position dependent and that the degree of amplitude variation is a function of the bend radius. It was found that the largest reflections are obtained from defects located close to the bend extrados; these were shown to be up to 4 times higher compared to the reflections from a defect of the same size in a straight pipe section. The exact position of the maximum reflection was also found to be dependent on the bend radius. Areas of lowest detectability were located on the bend intrados for all investigated radii; for some radii the reflection could be as low as 10% of that from the same defect in a straight pipe. The minimum reflections from defects located at the pipe extrados were shown to lie between 50% and 90% compared to a straight pipe defect, the lowest extrados sensitivity being on the smallest bend radius (1D) investigated.

The results of the Finite element study confirmed that the low reflection amplitude seen from a defect at a bend in an earlier study of a guided wave monitoring system was due to the location of the defect in the bend. This highlights a potential problem with guided wave inspection of bends unless the potential defect location is known in advance.

The results show that for circumferential cracks, the variation of the torsional guided wave inspection sensitivity around a bend follows the von Mises stress distribution. It is expected that a similar variation would be seen for small, roughly equiaxed corrosion defects, but the sensitivity to axial cracks would be very different as they do not affect the transmission of axial stresses. T(0,1) guided wave inspection is in general less sensitive to axial defects compared to defects which also exhibit some circumferential extent [34].
Acknowledgment

The authors would like to acknowledge the funding provided by the UK Engineering and Physical Sciences Research Council (ESPRC) and the UK Research Centre in Non-Destructive Evaluation (RCNDE) for funding an Engineering Doctorate studentship for S. Heinlein (EP/L022125/1 & EP/I017704/1), and Guided Ultrasonics Ltd for supporting this research.

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Highlights

- Reflection amplitudes from circumferential cracks in pipe bends were obtained from FE simulations.
- Strong variations in reflection amplitude with respect to defect position within the bend were observed.
- Circumferential crack reflections are shown to be proportional to squared von Mises stress at their location.
- The presented results explain low detectability of defects introduced on bends previously observed in a blind trial.