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Efficient defect detections in an elbow part of piping by guided waves using appropriate frequency 2
-FEM analyses and a method for efficient defect detections-
適切な周波数のガイド波でのエルボ部高感度欠陥検出 2 -有限要素解析と高感度検出法-

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1. Introduction

Guided wave inspection offers an efficient screening method for wall thinning of piping. However, signal interpretation becomes difficult when the wave propagation path includes an elbow although wall thinning frequently occurs around an elbow.

This paper shows the results of computer simulations that use the same configuration as the experiments in part 1 of this series of papers and analyzes propagation behavior of guided waves passing through an elbow. The simulation results indicate that the variation in guided wave amplitude by location at an elbow corresponds to defect sensitivity on each location. From this characteristic of defect sensitivity, we propose an efficient method of defect detection at an elbow.

2. FEM simulations of guided waves

In this study, the commercial simulation software ComWAVE was used to conduct computer simulations of guided waves. Our group has been dealing with simulations of guided waves with ComWAVE and verifying simulation results [1].

ComWAVE, developed by ITOCHU Techno-Solutions Corporation, is ultrasonic simulation software that deals with modeling, mesh generation, numerical computation and visualization of the results [2]. ComWAVE employs finite element method (FEM) using voxel elements. For computation by ComWAVE, a computational model is discretized into identical cubic elements (voxel elements). This simplifies the matrix formulation of FEM and reduces computation time and memory usage significantly. The time derivative of the equation to be solved is discretized by a second-order accurate central difference scheme. Then, the equation is solved with an explicit method.

Fig. 1 shows the configuration of the simulation model. The pipes are 50A Sch. 40 (60.5 mm in outer diameter and 3.9 mm in thickness). The shape of the long radius elbow adheres to JIS B2313 (comparable to ASME B16.9). The weld beads at both ends of the elbow are formed by several tori in the model. A weld bead on the outer surface is given by a torus with a major radius of 28 mm and a minor radius of 5 mm (only the part sticking out of the outer surface). A weld bead on the inner surface is given by a torus with a major radius of 26 mm and a minor radius of 2 mm.

The pipes are assumed to be made of aluminum. The velocities of longitudinal and shear waves in aluminum are set to 6,000 m/s and 3,120 m/s respectively. The density of aluminum is set to 2,700 kg/m^3. Materials properties are not defined in the other regions besides the pipe walls. These non-defined regions are treated as a perfect reflector. Computations are not performed inside these regions.

A transmitter is placed 485 mm before the inlet of the elbow. This transmitter consists of eight elements aligned on the outer surface of the pipe in the circumferential direction at regular intervals. All the elements simultaneously vibrate in the same circumferential direction to generate the

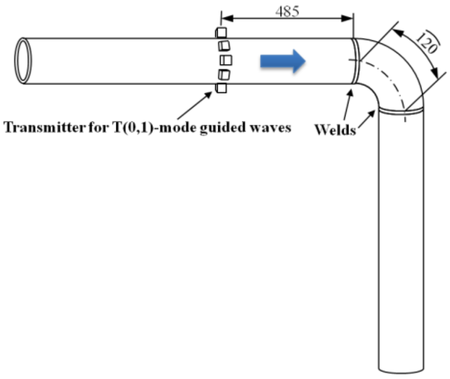

Fig. 1　The configuration of the simulation model

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fundamental torsional mode T(0,1). The amount of displacement of the transmitter elements for each time step is given as the input signal. The input signal is a 5-cycle pulse with a certain center frequency.

The whole computational model is built up with 0.5 mm voxels. Then, the actual outer diameter and thickness of the piping in the computational model become 60 mm and 4 mm respectively. The computations were performed on a 12-core computer with 96 GB of RAM.

3. Simulation results

Because ComWAVE calculates the output parameters at each time step, ComWAVE can display propagation of ultrasonic waves as transient changes in the distribution of displacement amplitude by ultrasonic waves.

Fig. 2 (a) shows a distribution of displacement amplitude of the outer surface of the piping at a certain moment. The color changes from blue to red as the displacement increases. In this picture, a wave packet is just passing through the elbow. To indicate the regions where the amplitude becomes high with a single picture, a distribution of the maximum amplitude over time at each element is used as shown in Fig. 2 (b). The volume rendering representation is taken to show a similar distribution, which means all the elements of the pipe walls are used to construct an image.

Fig. 3 shows the distributions of the maximum amplitude around the elbow when the center frequency of the input signal is 30, 40 and 50 kHz respectively. To emphasize the high-amplitude regions, the colors for the amplitudes less than the threshold value are not displayed. While the maximum amplitude of the input signal is 1 and the maximum value in the color map is 1.55, the threshold value is set to 0.7.

In Fig. 3, whereas the concave side of the elbow gets higher amplitudes for 30 kHz, the convex side of the elbow gets higher amplitudes for 40 and 50 kHz. These simulation results imply that the locations of high-amplitude regions at an elbow are changed depending on the frequency of the guided waves. This may be attributed to interference of guided waves at an elbow. Even if guided waves entering an elbow are coherent, the shape of the elbow gives rise to constructive and destructive interference of the guided waves. In this process, the wavelength, which is determined by the frequency, of guided waves changes how the guided waves interfere with each other.

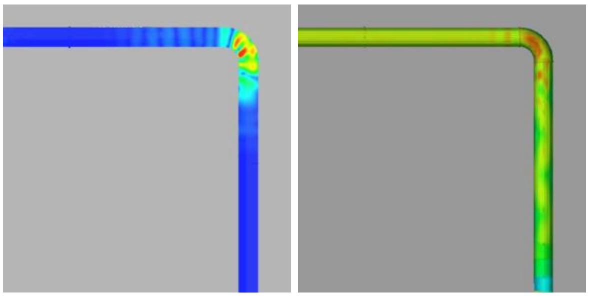
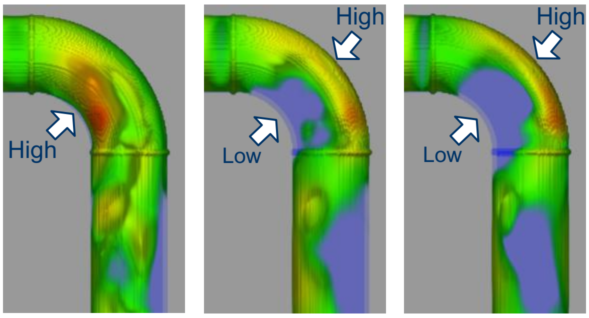

(a) transient (b) maximum

Fig. 2 Visualization of simulation results



(a) 30 kHz (b) 40 kHz (c) 50 kHz

Fig. 3 Distributions of maximum amplitude around the elbow

A high-amplitude region is expected to be a defect-sensitive region. In fact, the locations of high-amplitude regions in Fig. 3 correspond to the locations of high sensitivity obtained from the experiments in part 1 of this series of papers. Therefore, defect detection with high sensitivity at an elbow can be realized by choosing an appropriate frequency of guided waves based on simulation results.

4. Conclusion

Along with the experimental results in part 1, the simulation results show the locations of defect-sensitive regions are controlled by the frequency of guided waves and a proper selection of the frequency of guided waves realizes efficient defect detection at an elbow of piping.

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