2008 ultrasonic benchmark studies of interface curvature—a summary

Lester W. Schmerr Jr.
Iowa State University, lschmerr@iastate.edu

Ruiju Huang
Iowa State University

R. Raillon
CEA/LIST

S. Mahaut
CEA/LIST

N. Leymarie
CEA/LIST

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Abstract
In the 2008 QNDE ultrasonic benchmark session researchers from five different institutions around the world examined the influence that the curvature of a cylindrical fluid-solid interface has on the measured NDE immersion pulse-echo response of a flat-bottom hole (FBH) reflector. This was a repeat of a study conducted in the 2007 benchmark to try to determine the sources of differences seen in 2007 between model-based predictions and experiments. Here, we will summarize the results obtained in 2008 and analyze the model-based results and the experiments.

Keywords
ultrasonics, curvature measurement, nondestructive testing, Aerospace Engineering, QNDE

Disciplines
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Comments
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Authors
Lester W. Schmerr Jr., Ruiju Huang, R. Raillon, S. Mahaut, N. Leymarie, S. Lonne, S.-J. Song, H.-J. Kim, M. Spies, and V. Lupien
2008 ULTRASONIC BENCHMARK STUDIES OF INTERFACE CURVATURE – A SUMMARY

L. W. Schmerr, Jr.1,2, R. Huang1, R. Raillon3, S. Mahaut3, N. Leymarie3, S. Lonne3, S.-J. Song1, H.-J. Kim1, M. Spies5, and V. Lupien7

1Center for NDE, Iowa State University, Ames, IA 50011, USA
2Dept. of Aerospace Eng., Iowa State University, Ames, IA 50011, USA
3CEA/LIST, Saclay point courrier 120 F-91191 Gif sur Yvette Cedex France
4School of Mechanical Eng., Sungkyunkwan University, Suwon 440-746, KOREA
5Fraunhofer Institute for Techno- & Economy Mathematics ITWM, 67663 Kaiserslautern, Germany
6Acoustic Ideas, 27 Eaton Street, Wakefield, MA 01880

ABSTRACT. In the 2008 QNDE ultrasonic benchmark session researchers from five different institutions around the world examined the influence that the curvature of a cylindrical fluid-solid interface has on the measured NDE immersion pulse-echo response of a flat-bottom hole (FBH) reflector. This was a repeat of a study conducted in the 2007 benchmark to try to determine the sources of differences seen in 2007 between model-based predictions and experiments. Here, we will summarize the results obtained in 2008 and analyze the model-based results and the experiments.

Keywords: Ultrasonic Benchmark, Curvature Studies, Flat-Bottom Hole, Ultrasonic Measurement Model

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INTRODUCTION

When ultrasonic NDE flaw inspections are carried out in geometries where the sound must first pass through a curved fluid-solid interface before interacting with a flaw the curvature of the interface can have a profound effect on the measured flaw response. Thus, it is important to quantitatively determine how curvature affects the measurements in such cases. This is a problem where models can play an important role since the effects of interface curvature on the measured response are complex and it is expensive and time-consuming to evaluate curvature effects with calibration specimens and a purely experimental approach. In the 2007 QNDE ultrasonic benchmark session four groups from around the world compared model-based predictions to experiments for a series of pulse-echo immersion experiments where a focused transducer was used to measure the response of a flat-bottom hole (FBH) at normal incidence through a curved cylindrical interface, as shown in Fig. 1. Experiments were conducted with a number of aluminum test blocks with planar, concave, and convex cylindrical interfaces and the results compared to model-based predictions. In many cases there were significant differences seen between the model-based
results and experiments. In examining those differences, it was suggested that one source of error might be in the choice of transducer parameters [1]. Thus, in 2008 the 2007 experiments were repeated with a transducer whose parameters were thoroughly characterized. In addition, the distance, \(d_t\), (see Fig. 1) was reduced in 2008 to eliminate the possibility of some complex geometry effects, as will be discussed more below. Here, we will describe the results obtained in the 2008 benchmark under these new conditions.

**COMPARISON OF MODELS TO EXPERIMENTS**

In 2008, five groups participated in this ultrasonic benchmark study. The institutions represented were the Commissariat a l’Energie Atomique (CEA) in France, the Fraunhofer Institute for Techno- & Economy Mathematics (ITWM) in Germany, Sungkyunkwan University (SKKU) in Korea, the Center for NDE, Iowa State University (CNDE), in the United States, and Acoustic Ideas (AI), also in the United States. As in the 2007 benchmark, the experiments in the 2008 benchmark were conducted at CEA on a number of 0.8 mm diameter (#2) FBHs placed in aluminum blocks. For all tests the water path distance was fixed at the value \(d_t = 75\,\text{mm}\) (see Fig. 1) while the depths of the FBHs being considered had the values \(d_s = (6.35, 12.7, 19.05, 25.4, 38.1, 50.8, 76.2)\,\text{mm}\). One block had these FBHs located below a planar interface while two blocks contained a convex surface (\(R = +50.8\,\text{mm}\) and \(+203\,\text{mm}\) radius) and two others had a concave surface (\(R = -50.8\,\text{mm}\) and \(-203\,\text{mm}\)). The only difference between these parameters and those of the 2007 benchmark were that in 2007 the distance, \(d_t\), was twice the distance used here and the FBHs at the smallest and largest depths of the 2007 study (3.2 mm and 101.6 mm, respectively) were not considered in 2008. The change in the distance, \(d_t\), was made to avoid having multiple stationary wave paths from the transducer to the flaw and back. While it is unlikely that such multiple paths would significantly affect the model-based results, by simply reducing the water path distance the possibility of any influence of this
situation on the model predictions was eliminated. By removing the smallest and largest depth FBHs from the study, we also eliminated the two extreme cases where sources of experimental error might expected to be the largest. The most significant difference between the 2007 and the 2008 benchmarks, however, likely was in the transducer. In 2008, a well-characterized, focused transducer was provided by the Center for NDE, Iowa State University to be used in the tests. By well-characterized we mean that the values of transducer diameter and focal length used in the model-based studies were based on “effective” values that were obtained through extensive experiments and comparison with model-based predictions. The transducer used in 2008 was specified to have an effective diameter of 12.47 mm and an effective focal length of 172.9 mm. Another set of parameters that is important to specify correctly are the spectral characteristics (center frequency, bandwidth) of the measurement system. Strictly speaking these are a function of both the transducer(s) used in a measurement as well as the other electrical elements (pulser/receiver, cabling). However, the transducer frequency domain response often plays a dominant role in these parameters so that they are often referred to as the center frequency and bandwidth of the transducer. In this case, the center frequency was given as 4.8 MHz and the -6 dB bandwidth was given as 88% of this center frequency.

The other specified parameters of the measurements were as follows. The density of the water was taken as \( \rho_1 = 1 \text{ gm/cm}^3 \) and the compressional wave speed of the water was taken as \( c_{p1} = 1484 \text{ m/sec} \) while the aluminum properties were given as \( \rho_2 = 2.7 \text{ gm/cm}^3 \), \( c_{p2} = 6381.2 \text{ m/sec} \), \( c_{s2} = 3000 \text{ m/sec} \) for the density and compressional and shear wave speeds, respectively. In the 2008 study the reference FBH response was taken to be the FBH located 12.7 mm below the test block with a planar interface. This is in contrast to the 2007 study where the FBH 3.2 mm below the planar surface was used instead. Again, this change should help reduce the possibility of experimental error since the FBH reference in this case is not near the interface where competing signals can be present. The amplitude of the rectified A-scan signal from this reference was measured. Then the ratio, \( C_{\text{ref}}(R,d_2) \), in decibels was calculated experimentally based on the measured amplitude of the rectified response of a hole at depth, \( d_2 \), in a block with a radius \( R \), \( A(d_2,R) \), and the reference planar surface FBH response, \( A(12.7,\infty) \):

\[
C_{\text{ref}}(d_2,R) = 20 \log_{10} \left[ \frac{A(d_2,R)}{A(12.7,\infty)} \right] - [G(d_2,R) - G(12.7,\infty)]
\]  

Equation (1) also compensates for any changes present in the system gain setting, \( G(d_2,R) \) (in decibels) for the measured FBH response setup and the gain setting \( G(12.7,\infty) \) used in the reference setup.

The objective of this study was to use ultrasonic models to estimate a ratio, \( C_{\text{model}}(R,d_2) \), corresponding to Eq. (1) and compare those predictions to their measured values, which were obtained from the experiments conducted at CEA.

The beam models and flaw scattering models used in four of the five groups participating in the 2007 benchmark were described previously [1] so they will not be repeated here. The beam model used by Acoustic ideas in the 2008 benchmark is based on integration of a time domain geometrical acoustics solution that accounts for surface curvature effects and plane wave transmission coefficients at each surface interaction as described for example in [2]. The model is supplemented by the use of caustic corrections.
and a solution of Biot and Tolstoy for the diffraction of a wedge [3], as a building block for computing diffracted contributions from arbitrary three-dimensional shapes. This approach is currently being implemented in a commercial ultrasonics package called Ultrasonic Modeler™ [4]. In the model-based results of Acoustic Ideas presented here, the flaw was considered as a simple delta function point source, so that the more detailed flaw scattering model based on the Biot-Tolstoy solution was not included in the calculations. However,
caustic corrections were used. Figure 2 shows a comparison of the experimental results (EXP) and model-based results obtained by the various groups for the test block with the planar interface. The dashed lines show the bounds for a ±1 dB deviation from the experimental values. Variations of 1 dB or more are often found in ultrasonic tests from a variety of uncertainties so staying within these bounds is an indication of "good" agreement of the models with the experiments. It can be seen from Fig. 2 that except for the FBHs at the smallest and largest depths, all the model results matched to within a few tenths of a dB to the experimental values. In contrast, in 2007, differences as large as 4 dB were present for this case.

Figure 3 shows a similar comparison for the block with the 50.8 mm concave radius interface. This case is likely the most severe test present in this study since the curved surface is a rather tight focusing interface. There were certainly larger differences seen here from those seen for the planar interface, but except for some isolated cases the consistently very large differences (> 7 dB) found by all the modelers in 2007 were not present here, as can be seen from Fig. 3.

Figure 4 shows the comparison of model-based results to experiments for the 50.8 mm convex interface. In 2007 this case showed some of the most consistent results with most differences lying within the ±1 dB error bounds. As seen in Fig. 4 this was also true of the 2008 study but for the FBH at the smallest depth all the models consistently predicted results outside these bounds and there were also some larger differences seen for the FBH at the largest depth.

Figures 5 and 6 show the results for the test blocks with a 203 mm concave and convex interfaces, respectively. In the 2007 study, model-based predictions these cases were in relatively good agreement with experiments and as can be seen from both Fig. 5 and Fig. 6 this was also the case in the 2008 study. All model results, however, were again higher than the experimental values for the FBH at the smallest depth and outside the ±1 dB bounds for the concave 203 mm interface case of Fig. 5. This suggests that there may be
FIGURE 5. Comparison of the measured responses of FBHs through a 203 mm concave interface (EXP) with model-based results (various symbols). The dashed lines show ±1 dB error bounds from the experimental values, which are shown as circles.

FIGURE 6. Comparison of the measured responses of FBHs through a 203 mm convex interface (EXP) with model-based results (various symbols). The dashed lines show ±1 dB error bounds from the experimental values, which are shown as circles.

...some consistent source of error in this near-surface case. In all the other cases, however, very good agreement was found, with many differences being only a few tenths of a dB.
SUMMARY AND DISCUSSION

In the summary of the 2007 benchmark study of interface curvature effects it was suggested that the very large differences seen between model-based results and experiments in that study might have been due to the choice of parameters used for the transducer. By repeating the same interface curvature study in 2008 with a well-characterized transducer where effective diameter and focal length parameters of the transducer were obtained experimentally to ensure that they reproduced well the observed sound beam of the transducer, the agreement between the models and experiments was indeed significantly improved in the 2008 benchmark study. Some other relatively minor changes in the setup parameters also may have contributed to the better agreement found in 2008. Although a variety of beam models and flaw scattering models were used by the groups participating in this 2008 study, in many cases all the models were in very good agreement with each other and with experiment.

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REFERENCES


4. www.acousticideash.com