World Federation of NDE Centers

2004
ULTRASONIC BENCHMARKS

BACKGROUND

At the last three Review of Progress in Quantitative Nondestructive Evaluation Conferences, the World Federation of NDE Centers has sponsored a series of NDE benchmarking sessions. These sessions were designed to allow NDE researchers from around the world to model some specific NDE problems and compare their results. For more details of the problems considered at these sessions, see:

Review of Progress in Quantitative Nondestructive Evaluation, D.O. Thompson and D.E. Chimenti, Eds., American Institute of Physics, Melville, N.Y. , Vols. 21, 22, 23.

In the ultrasonic benchmarking studies performed to date the various models used have generally agreed to within 1-2 dB of each other in terms of predicted relative peak-to-peak responses of various reflectors such as flat-bottom holes, side-drilled holes, and spherical voids. To date, these results have involved only model-to-model comparisons, so the next step will involve experimental validation studies.

2004 BENCHMARKING STUDIES

As a next phase of these benchmarking activities, the Center for NDE, Iowa State University, has conducted a series of experimental studies to allow a more direct validation of ultrasonic models in some simple testing situations. The experimental studies all initially involve immersion pulse-echo setups where the reflector (flat-bottom hole, side-drilled hole, or spherical pore) is interrogated with either a planar or a spherically focused transducer.

We would like you to join in our benchmarking activities by modeling these selected problems and comparing your model results to the experimental results.

We are initially posting the results of our experiments on the CNDE ftpsite (ftp.cnde.iastate.edu) in the folder named 2004_UT_Benchmarks, located in the public directory folder named Pub. You can download these files and the overview file named READ ME which will give data formats and other pertinent information. Below we have also outlined the cases involved in more detail.

If you decide to participate in these comparisons, please e-mail Prof. Lester W. Schmerr at the Center for NDE, Iowa State University (lschmerr@cnde.iastate.edu) to indicate that you are working on these problems. If you have any problems or questions, please contact Prof. Schmerr.

We also would like to invite you to participate in the next Review of Progress in Quantitative NDE meeting, which will be held in Golden Colorado, July 25-30, 2004. We plan to hold an ultrasonic benchmarking session at that meeting on these problems. We would encourage you to submit an abstract to that session on your results for these problems. Please indicate on your abstract that the talk is designated for the Ultrasonic Benchmark session. For more details on the conference, go to the CNDE website www.cnde.iastate.edu

Regardless of whether you are able to attend this meeting or not, we would like you to also give us a summary of your results that we could post on the Web. More details of this request are given below.

2004 Benchmark Problems

We have measured the pulse-echo immersion response of three types of reference reflectors using either a planar or a spherically focused transducer .

The three reflector types were: a side-drilled hole, a flat-bottom hole, and a spherical pore (void).

In all these cases we obtained the pulse-echo A-scan responses of the reflectors and also the pulse-echo response from a front-surface reflection from the test block. More details of the actual cases considered are given below.

Side-drilled hole (SDH) Specimens

We manufactured two aluminum SDH blocks. One contains a 1 mm diameter SDH and the other a 4 mm diameter SDH, both at the 25.4 mm depth shown in Fig.1(the depth is measured to the center of the hole). In both cases the A-scan response of the SDH was obtained at various refracted angles (θ = 0, 30, 45, 60, and 70 or 75 degrees) for both P-waves and SV-waves. For each block a reference A-scan response (at the same system settings as for the SDH responses) was obtained from the front surface of the block at normal incidence in the setup shown in Fig. 2. Note the water path was held fixed at 50.8 mm in all these cases.

Note that the SDH reflector may not lie on the central axis refracted ray of the transducer as Fig. 1 seems to imply since the experimental results were obtained by peaking up the amplitude of the received signal and at oblique incidence the incident wave field maximum may not occur on that central axis ray (see also Some Remarks on page 9).

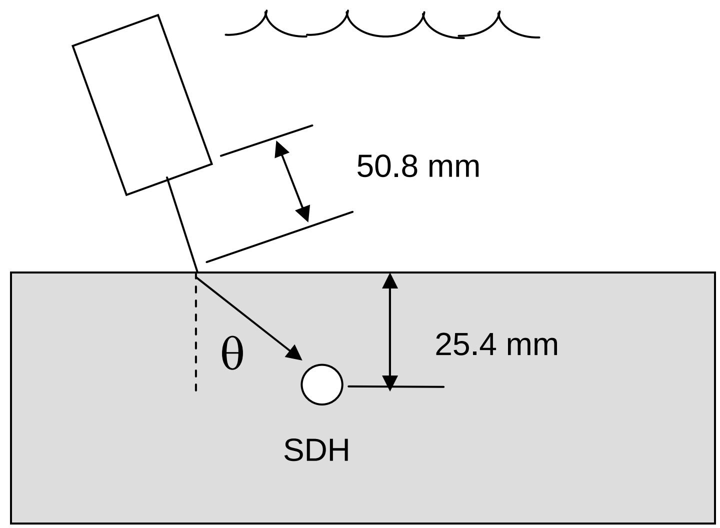


Fig. 1 Planar Transducer setup for SDH specimens

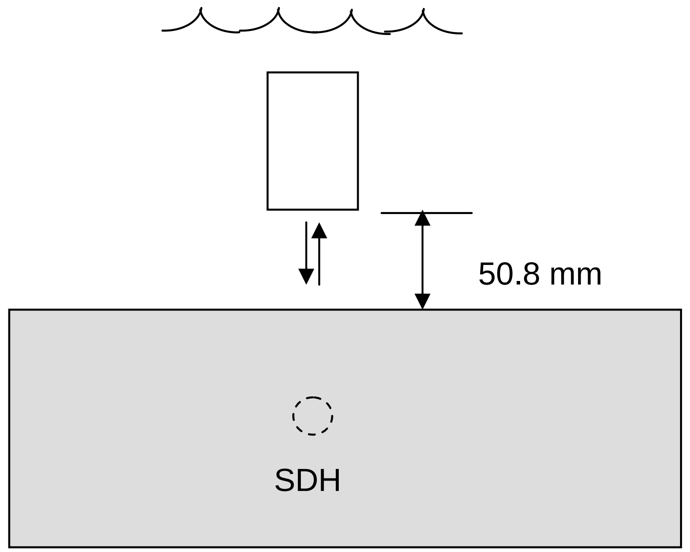


Fig. 2 Reference experiment for a planar transducer and SDH specimens
(planar front surface reflection)

The I mm and 4 mm SDHs were also interrogated with a spherically focused transducer (geometrical focal length of 172.9 mm) as shown in Fig. 3

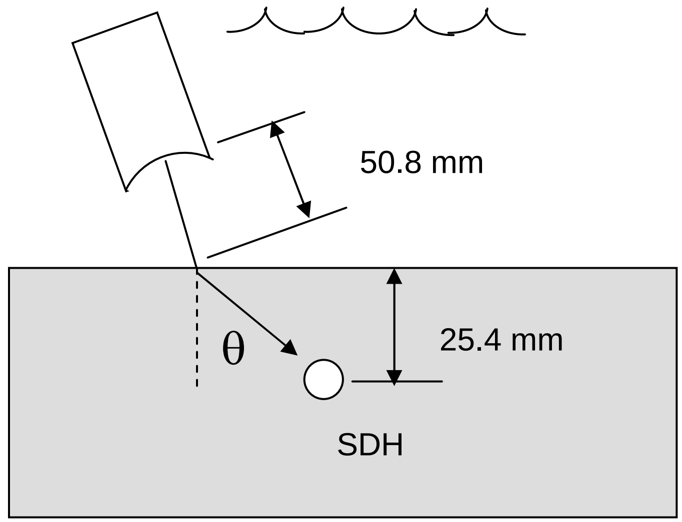


Fig. 3 Spherically focused transducer setup for SDH specimens

Again, the A-scan response of the SDH was obtained at various refracted angles (θ = 0, 30, 45, 60, and 70 or 75 degrees) for both P-waves and SV-waves with a water path length of 50.8 mm.

For the spherically focused probe, a reference scattering experiment was again performed at the same system settings as the for the SDH cases. However, in this case the transducer was placed at a water path length equal to the geometrical focal length of the transducer, as shown in Fig. 4, and the A-scan response of the front surface was measured at normal incidence.

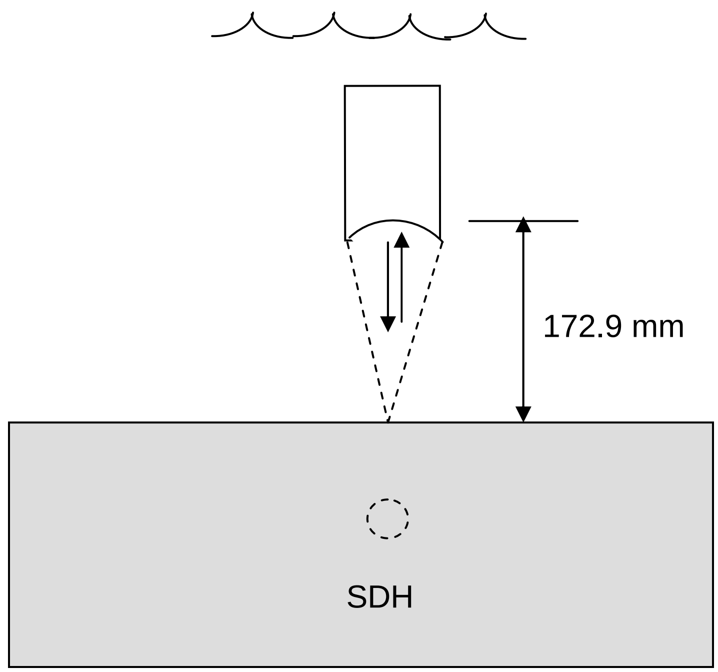


Fig. 4 Reference experiment for spherically focused probe and SDH specimens

Flat-bottom hole (FBH) specimen

An ASTM resolution block (1018 steel) was used as the test specimen for the FBH measurements. In this specimen, only the case where the transducer was normal to the interface was considered, for a planar probe as shown in Fig. 5. The A-scan response of a #3, #5, and #8 FBH were obtained from this specimen and a reference A-scan response from the front surface was again obtained in the same fashion as in the SDH case (see Fig. 2). The FBH was located in these experiments on the central axis of the transducer.

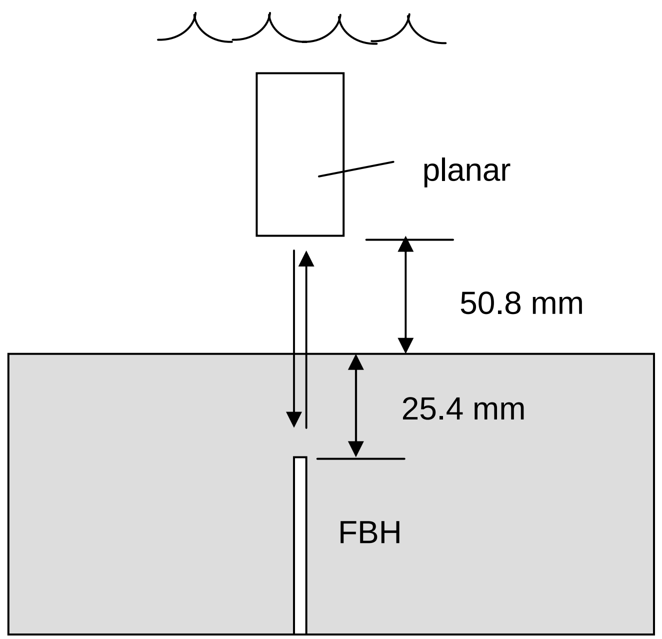


Fig. 5 Planar transducer setup for the FBH specimen

Spherical Pore Specimen

A specimen made of fused quartz and containing a 692 μm diameter spherical pore was used for these measurements, as shown in Fig.6. In this case, like the FBH case, the transducer was always normal to the interface and the transducer was either a planar or a spherically focused probe. The transducer was positioned so that the pore was on its central axis. The depth shown is to the center of the pore.

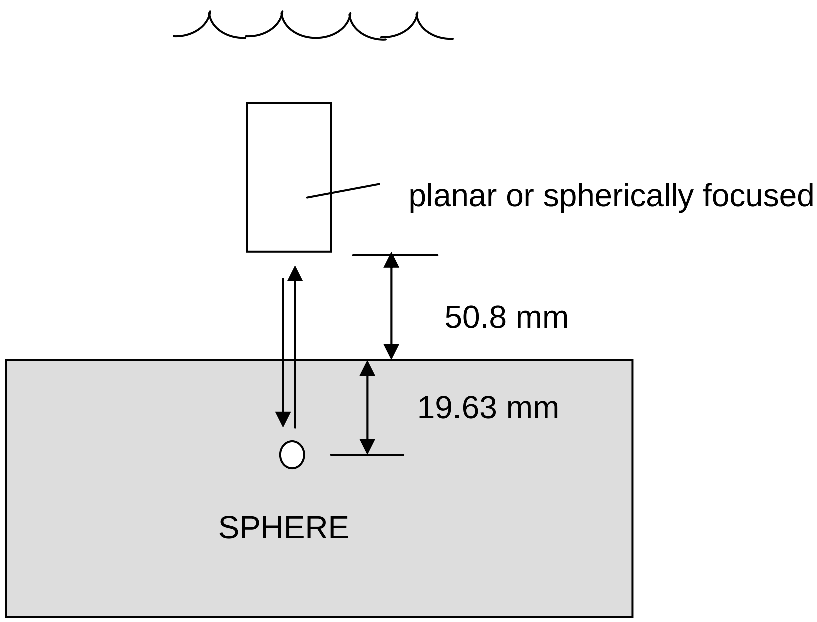


Fig. 6 Planar and focused transducer setups for the spherical pore specimen

Front surface reference responses were also obtained here for the fused quartz specimen, in exactly the same configurations shown previously in Figs. 2 and 4 for the planar and spherically focused probes, respectively.

Some remarks:

The attenuation of the water (at the temperature under which all the experiments were conducted) was calculated as

$$\alpha = 0.2479 \times 10^{-3} \ f^{2}$$

Np/cm

where f is the frequency in MHz

In all the testing cases the transducer location and orientation was changed until a maximum response was obtained. For the normal incidence setups, this likely means that the reflector is on the central axis of the transducer. For the oblique incidence SDH cases, one can assume that the incident wave direction is perpendicular to the axis of the SDH, but the reflector may not lie on the central axis refracted ray of the transducer as Figs. 1 and 3 seem to imply since the maximum point for the incident wave field may not occur on that central ray .

The P-wave attenuation of one of the aluminum blocks was measured but found to be negligible for these problems, so that further attenuation measurements were not performed on the second block. We expect that the steel block attenuation also is negligible, but no tests were done to verify that assumption. Similarly, the fused quartz attenuation was assumed to be negligible.

The widths of all the blocks were sufficiently large to eliminate any effects of side-wall reflections. Thus, in the case of the SDH, for example, one can assume that the SDH effectively appears infinite in length.

The focal length and diameter values given for the spherically focused probe are "effective" values obtained by matching the response of the transducer in the water bath to model-based results. Thus, these values can be used directly as the diameter and geometrical focal length in your model. The planar probe diameters are just the nominal diameters as given by the manufacturer.

The A-scan and other data for these various cases is located in the folder hierarchy shown in Fig. 7. The READ ME text file contains a copy of these notes. The results are separated into sub-folders according to 1) the type of "flaw" (FBH, SDH, or SPH) and 2) type of transducer (FOCUSED or PLANAR). In the SDH case, since separate blocks were manufactured for the 1mm and 4 mm SDHs the results for these two flaw sizes were placed in separate sub-folders BLOCK 1 and BLOCK 2. The refracted P- and S-wave responses were obtained separately for each of these blocks so that there is also a set of sub-folders labeled P-waves and S-waves as shown in Fig. 7.

The files in each of the final sub-folders include a text file named PARAMETERS.txt that lists all the pertinent parameters (wave speeds, transducer properties, etc.) for the experimental results of that final sub-folder.

In each final sub-folder a text file containing the A-scan results from a front-surface reflection experiment, as described previously, is in a file named REF.txt. This front surface reflection measurement was performed at exactly the same system settings used for the other A-scan measurements contained in the same sub-folder.

Finally, in each final sub-folder all the A-scan results for the cases considered are contained in text files having a naming convention that will be described below.

The A-scan data are all contained in text files. The format of those files is very simple. It is just a two column format, where the sampled time values (in μsec) are given in the first column and the measured A-scan voltage (in volts) is given in the second column, separated by a tab, i.e.

t1	v1
t2	v2
t3	v3

etc.

All A-scan data contain 1000 sampled points. The sampling frequency used was always 100 MHz.

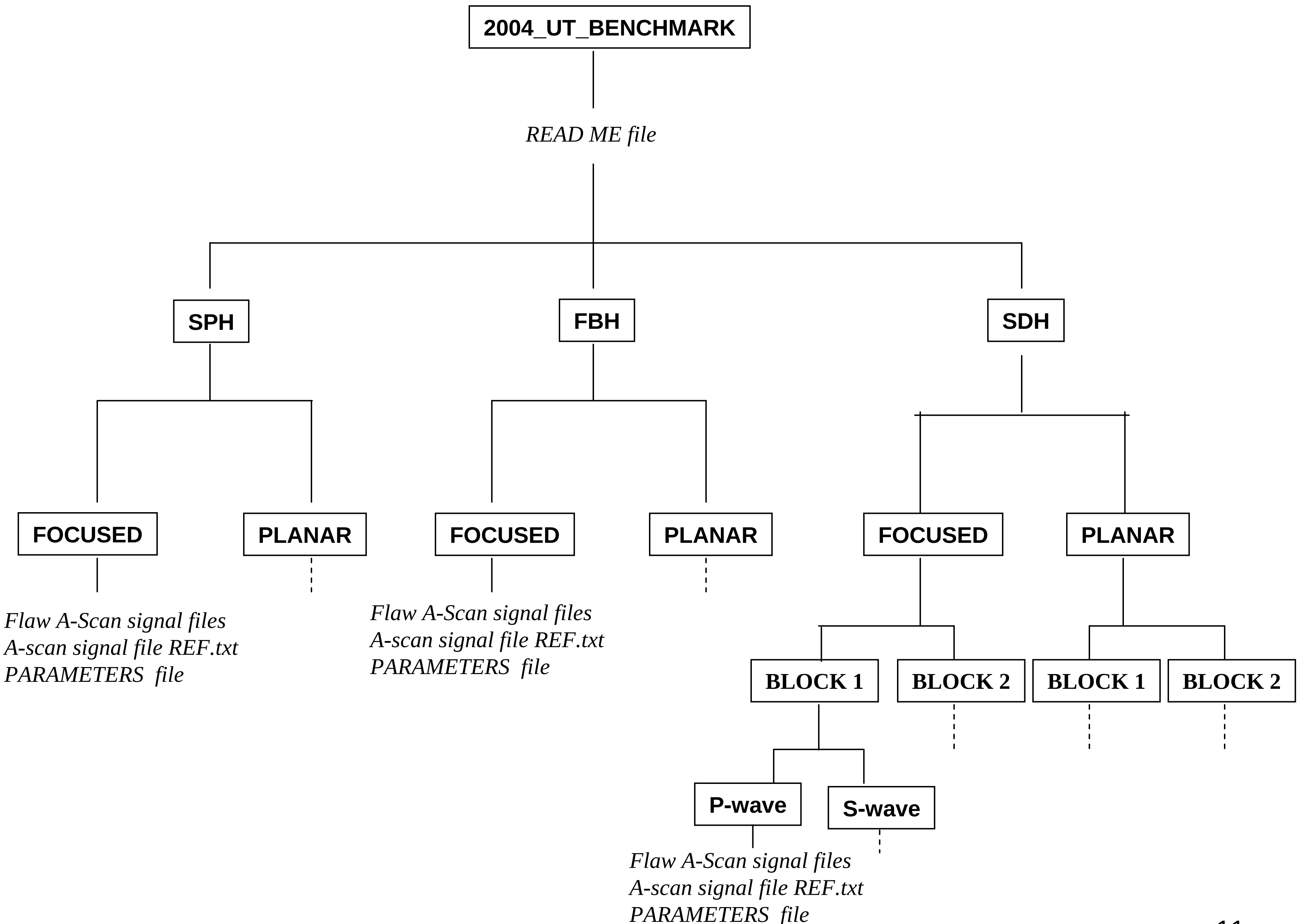


Fig. 7 The file structure for the 2004 ultrasonic benchmark data

All the data files for the A-scan responses of the reflectors in the various cases considered follow the following format.

File name format for a "flaw" A-scan signal files

P_45_U_4_FBH.txt

wave type incident on the reflector (P or S)

refracted angle (deg)

transducer type (U = unfocused (planar) , F = focused)

reflector size (Examples: 4 = 4 mm diameter,
n5 = 5/64 in. diameter (e.g. number 5 FBH)
s1 = sphere one (actual size given in PARAMETERS file))

reflector type (flat-bottom hole (FBH), side-drilled hole (SDH), or spherical pore (SPH)

The file PARAMETERS.txt contains a comprehensive list of all the parameters needed to model a given setup (those that are not contained in the data filename just shown). The parameters contained in this text file are listed below.

Parameters given in PARAMETERS.txt

Transducer
Transducer center frequency (MHz)
transducer diameter (mm)
transducer focal length (effective geometrical value) (mm)

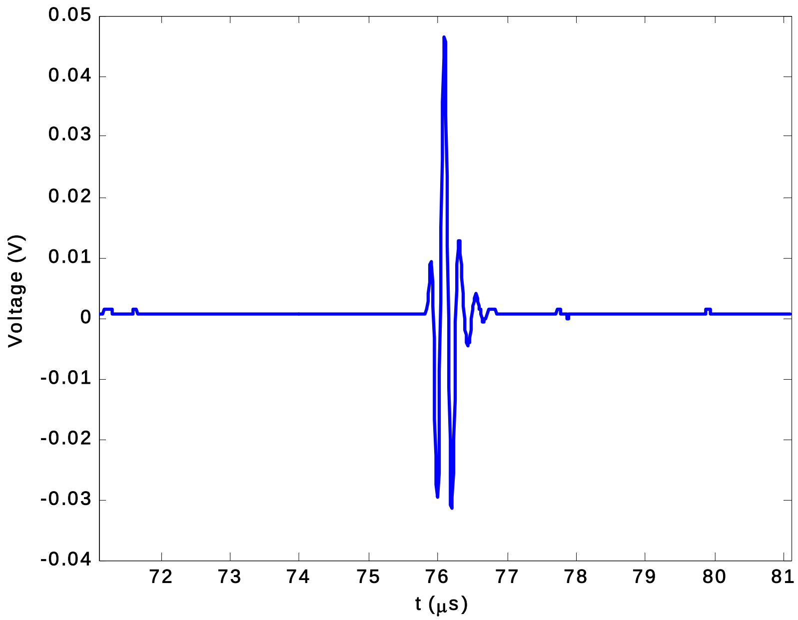
Geometry-Setup
water path (mm)
reflector depth (normal to the interface – to reflector center (or front surface for the FBH)) (mm)

Material Properties
velocity of water (mm/μsec)
density of water (gm/cm$^{3)}$
attenuation of water $\alpha = 0.2479 \times 10^{-3} \ f^2$ Np/cm
P- wave speed of block (mm/μsec)
S- wave speed of block (mm/μsec)
density of block (gm/cm$^{3)}$

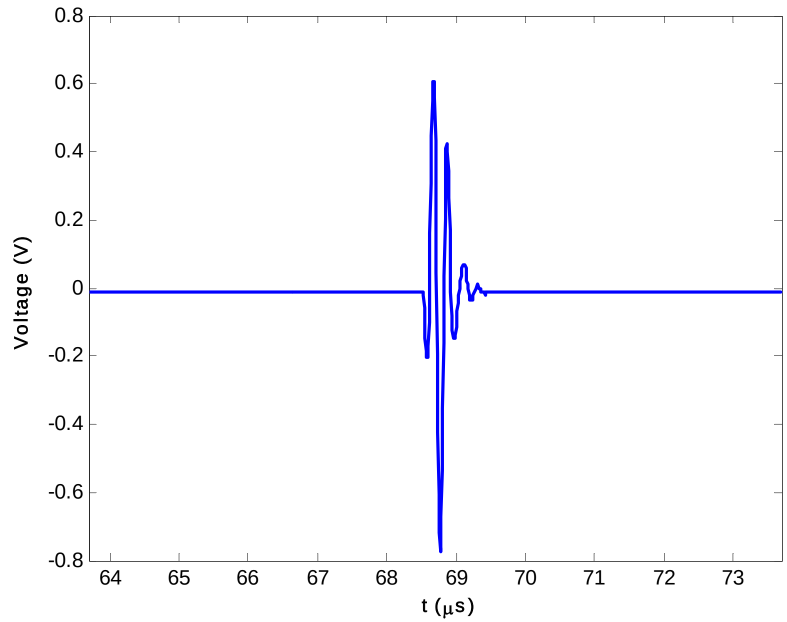
Data
sampling frequency (100 MHz)
Number of data points in A-scans (1000)

Flaw
diameter (mm) -pore case only

The PARAMETERS.txt file also contains an example A-scan waveform for one of the cases considered in that subfolder as well as the wave form contained in the REF.txt file in that same subfolder. For example:



P_0_U_4_SDH



Reference signal waveform

The flaw data sets currently available are as follows:

side drilled holes

P_0,30,45,60,75_U_4_SDH

S_30,45,60,75_U_4_SDH

P_0,30,45,60,75_F_4_SDH

S_30,45,60,75_F_4_SDH

P_0,30,45,60,70_U_1_SDH

S_30,45,60,75_U_1_SDH

P_0,30,45,60,70_F_1_SDH

S_30,45,60,70_F_1_SDH

flat-bottom holes

P_0_U_n3,n5,n8_FBH

spherical pores

P_0_U_s1_SPH

P_0_F_s1_SPH

This is a large number of cases. However, there are certain ones that are more challenging to model than others. Thus, the following data sets are the <u>primary</u> ones we would like to cover in the 2004 benchmark studies:

P_0,45, 75_U_4_SDH

S_30, 60,75_U_4_SDH

P_0, 45, 75_F_4_SDH

S_30,60,75_F_4_SDH

P_0,45,70_U_1_SDH

S_30,45,60_U_1_SDH

S_30,45,60_F_1_SDH

P_0_U_n8_FBH

P_0_U_S1_SPH

P_0_F_S1_SPH

The 2004 Ultrasonic Benchmark Problem

For the 2004 benchmark problem we would like to perform the following model-based/experimental studies and comparisons:

1. Model the complete A-scan responses of the 24 primary cases listed on the previous page and compare to the measured A-scan signals.

a. Make absolute comparisons of your model-based A-scan wave forms to the experimental wave forms given. If you cannot make an absolute comparison, specify the normalization procedure used to make relative comparisons.

b. In the 4 mm SDH cases, take as a reference the planar transducer normal incidence P-wave voltage response (P_0_U_4_SDH) and compute ratios of the peak-to-peak voltage responses of the other 4 mm SDH cases to that reference response. Examine differences between the model and experimental peak-to-peak ratio values in the following cases:

I. 30 degree SV-wave responses (this is near the critical angle for P-waves)
II. 45 degree P-wave and 60 degree SV wave responses (these are all nominally "benign" cases)
III. 75 degree P-wave and SV-wave responses (high refracted angle cases)

c. For the 1 mm SDH case, model the case I. (critical angle) and case II. relative peak-to-peak voltage responses in the same fashion. There are no high refracted angle cases in the 24 primary cases, so this comparison is omitted.

These comparisons should be a good exercise of the models under different testing conditions.

2. Taking as a reference the normal incidence planar probe 4 mm SDH case (P_0,45, 75_U_4_SDH), compute the relative peak-to-peak voltage responses for all the other normal incidence SDH, FBH and SPH responses and compare to the experimentally observed ratios.

This should test the models across different flaw types.

3. For each of the twelve 4 mm SDH cases, at a fixed frequency (the center frequency of the transducer) plot the magnitude of the incident wave field velocity, v_z, versus the x- and y-directions (perpendicular to the refracted ray which is along the z-axis - see Fig. 8 below) where the origin is located at the center of the flaw). Assume the wave field is generated by a piston transducer whose velocity, v_0, is unity on the transducer face, as shown in Fig. 8.

The purpose of this study is to compare directly the model-based predictions (from different modeling approaches) of these incident wave fields at the flaw, which, of course, are a key aspect of modeling the flaw responses. This may help us to understand where modeling differences, if any, may occur.

4. Model any of the other available cases as time permits

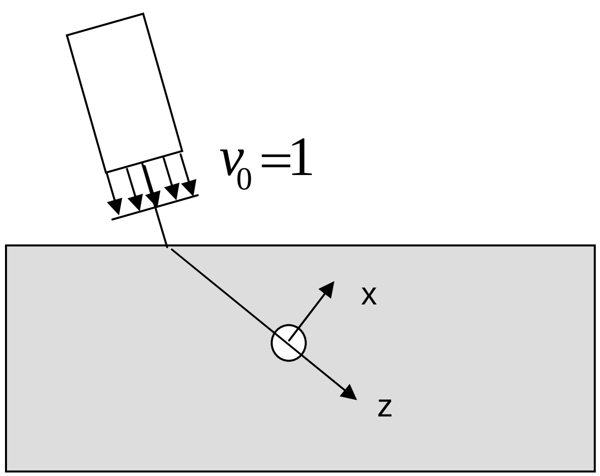


Fig. 8 Definition of coordinates for incident beam model calculations

PRESENTATION OF RESULTS

Ideally, we would like you to present your results and discuss them at the benchmarking session we plan to hold at the next Review of Progress in Quantitative NDE meeting in July. Please e-mail Prof. Schmerr (lschmerr@cnde.iastate.edu) if you plan to attend and participate in this session.

We would also ask you to make a summary of your results and place them in a pdf file that we could post on the World Federation of NDE Centers website (www.wfndec.org). If possible, please e-mail Prof. Schmerr your results in this form as soon as they are available, even if it is before the Review of Progress in Quantitative NDE meeting and even if you cannot attend the meeting.

I am sure the members of the World Federation of NDE Centers will agree with me that your participation in these benchmarking activities is greatly appreciated. We feel that by making such comparisons we can demonstrate to the world-wide NDE community the capability modeling has to predict the signals we see in actual tests. Such comparisons will also aid in the process of making modeling an accepted engineering tool in the NDE field.

Les Schmerr
Permanent Secretary, World Federation of NDE Centers
April, 2004