Transaction Agreement DTRS56-02-T-0007
Modification #4 (Aug 31, 2004)

DOE National Energy Technology Laboratory Technology Demonstration Program

Battelle - West Jefferson Facility
Blind Guided Wave Verification Exercise
Report of Results

September 13 – 17, 2004

For questions or comments concerning this report, please contact:

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DOE/DOT Technology Demonstrations

Test Evaluation Summary

1. *What was your overall opinion of this demonstration event? (positive & negative opinions)*

Our Group felt that the test was well organized and efficient. Although there was some very minor inconvenience in sharing test samples with another operator, this did not have any substantial effect on our ability to carry out our inspections.

2. *Did you have any difficulties setting up your equipment?*

No, other than having equipment delayed in transit by Federal Express.

3. *How efficiently did your calibration and data collection runs work out?*

We did not have any problems calibrating and collecting data. However, it should be noted that the calibration defects for guided wave could have been placed at better positions on the pipe sections, i.e., at distances at least 5 -10 feet away from the set-up position. Secondly, guided wave results can be affected by the cut end of a pie and better results are obtained when the inspection collar is mounted a minimum of 5 feet away from the end of the pipe.

4. *Did you feel this demonstration was a fair test of your technology?*

Yes, except the sample with the natural corrosion had too much corrosion over the entire length of the pipe. Some clear areas along the section would have shown the capability of the guided wave technique to delineate corroded areas from clear areas.

5. *Would you welcome further opportunities to demonstrate your technology?*

Yes!

6. *If the demonstration test were repeated in 12-18 months what changes would you suggest?*

For the guided wave test, the sample should be longer and allow for a mid-section set-up as well as on the ends. Secondly, the test would be much more representative of actual field conditions if the pipe was buried and coated.

Introduction

At the request of the RSPA Division of the US Department of Transportation the PetroChem, Plant Integrity, Penn State and FBS Research Team was requested to participate in a pipeline inspection technology verification exercise sponsored by the US Department of Energy. Two 12 inch OD test pipes were examined by the PetroChem Team at Battelle's West Jefferson, OH pipeline test facility. Other samples were also available and were used by the different technologies participating in this exercise. The *Teletest*® long range guided wave ultrasonic system in its most advanced configuration was used to examine the pipe samples. The tests were carried out as part of a program to benchmark emerging pipeline inspection technologies. One of the pipes inspected contained machined defects while the other contained naturally occurring corrosion defects on an on coated section of retired pipe. This report contains the findings from these tests.

The long range guided wave technique

The *Teletest*® technique has been developed for the rapid survey of pipes, for the detection of both internal and external corrosion. The principal advantage is that long lengths, ~100ft or more in each direction, may be examined from a single test point. The benefits are:

- Reduction in the costs of gaining access to the pipes for inspection,
- The ability to inspect inaccessible areas, such as buried and sleeved pipes, at clamps, under supports and through berms, dikes and wall penetrations,
- Avoidance of removal and reinstallation of insulation or coatings (where present), except for the area on which the transducers are mounted,
- The whole pipe wall is tested, thereby achieving a 100% examination.

Long-range ultrasonic methods use so-called guided ultrasonic waves. These are similar to the Lamb waves, which may be generated in plates, and in common pipe thicknesses are necessarily of much lower frequency than that used for normal ultrasonic tests in order to generate the appropriate wave modes. Typically frequencies around usually between 30 and 75 kHz are used compared with around 5MHz for conventional thickness testing. These waves have the property that they can travel many meters with minimal attenuation and therefore offer the potential of testing long distances from a single point using a pulse-echo transducer bracelet wrapped around the pipe. Any changes in the thickness of the pipe, either on the inside or the outside, cause reflections that are detected by the transducer. Hence metal loss defects from inside or on the outside of the pipe can be detected. The detection of additional mode converted signals from defects aids discrimination between pipe features and metal loss.

An important point to note is that the long range techniques currently available are screening tools and do not provide the same kind of resolution as local thickness measurements. The aim is to provide a rapid method of screening at a limited number of access points so that more appropriate test methods may be directed at areas requiring further attention. Most importantly, long range UT does not provide a direct measurement of wall thickness, but is sensitive to metal loss where depth, circumferential extent and the axial length to a lesser degree produce signal responses for interpretation. This is due to the transmission of a circular wave along the pipe wall, which interacts with the annular cross-section at each point. It is the reduction or increase in this cross-section to which the long-range technique is sensitive.

Some enhanced procedures, developed under funding from RSPA and DOT, have been applied which increase the information obtained from defects present in the pipes. These involve scanning and tuning of the test frequency and focusing of the ultrasound at a specific defect location.

Introduction to TeleTest Data Acquisition at Battelle Columbus

Figures 1 and 2 shows the locations of calibration and grading regions for the pipe samples examined at the Battelle, West Jefferson test site. This convention was supplied by the test managers at Battelle. The guided wave transducer array was placed 4.92' from End A of the pipe with manufactured defects and 3.58' and 46.26' from End A of the pipe with natural defects. These positions were used to perform axisymmetric (initial scans) and focused ultrasonic examinations of the pipes

Experimental Results

Because the distribution of ultrasonic energy within a pipe wall is highly frequency-dependent, guided waves with different excitation frequencies have different sensitivities to defects. Frequency tuning is able to help achieve a relatively high defect sensitivity. Therefore, frequency tuning experiments were carried out as the first step in our tests. The envelope of signal amplitude variation with excitation frequency is shown in Figures 3 and 4. The axial locations of defects can be determined from these figures.

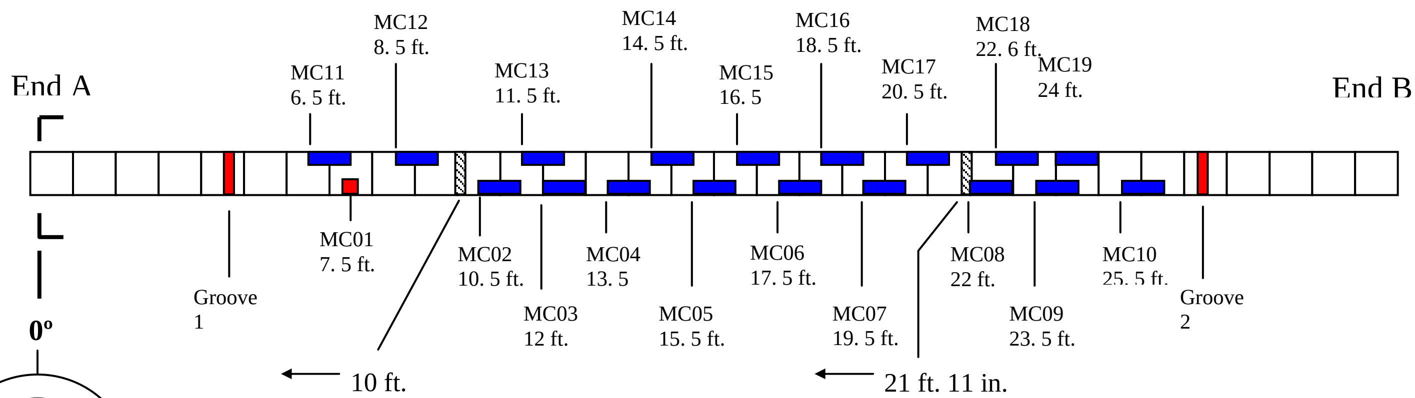
The phased array focusing technique can improve the energy impinging onto a defect as well as reduce the energy elsewhere around the circumference. Hence the focusing technique can not only improve sensitivity but also reduce the false alarm rate. In addition, focusing can provide an estimation of the circumferential position of a defect. In our experiments, we moved the focal spots around the pipe at all the assigned inspection regions. Our estimations of the defect location and approximate sizing are listed in Table 1-6. If the echoes from the defects were above the –26 dB level (referenced to the back wall amplitude), we called them "significant" defects; if the echoes from the defects were visible but below this level, we called them "insignificant" defects. There were no recognizable defect echoes in the so-called "clean" areas. Research on a method to utilize focusing phenomenon for defect sizing is still underway. Hence, the defect sizes estimated here are approximate. Axisymmetric inspection results with the T [0,1] (1^{st} torsional) mode at 35kHz are displayed in Figures 5(a)-(c). A sample focusing inspection result can be seen in Figures 6(a)-(d). Figure 6 shows that there is a defect (MC05) located at 270º at 16.1' from the pipe end A. By comparing to the axisymmetric signal in Figure 5, we observed that the amplitude of the defect echo increased by 6dB when focusing on the defect.

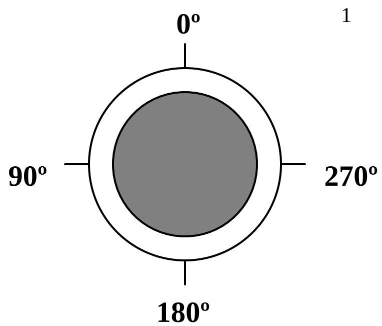
The inspection results for the machined defect pipe clearly show the exact axial and circumferential locations of the defects. Although the widely distributed corrosion in the natural defect pipe makes diagnosis of each individual area difficult, we can distinctly determine that the pipe is heavily corroded with four corrosion regions: 1) [2 feet ~9 feet], 2) [11.5 feet ~18 feet], 3) [28 feet ~ 36 feet], and 4) [37 feet ~41 feet]

Acknowledgements

The results contained in this report were compiled by Li Zhang, a PhD candidate in Guided Wave Ultrasonic Technology from The Pennsylvania State University working under the direction of Dr. Joseph Rose. Dr. Mike Avioli, with FBS provided assistance with data acquisition, analysis and software support. Peter Mudge with Plant Integrity advised the team on data acquisition, equipment setup and assisted in the collection and final review of the data. Plant Integrity, Ltd. and PetroChem Inspection Services contributed additional equipment to the exercise that was needed to inspect the 12” diameter pipes.

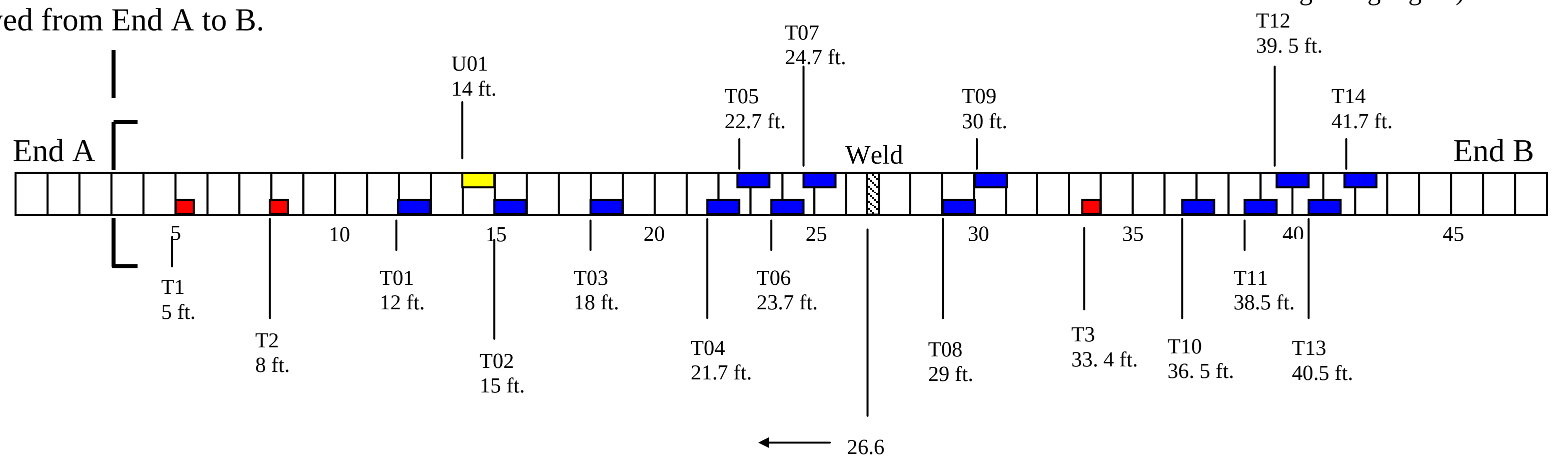
Figure 1. Schematic of calibration and grading regions for the pipe with machined defects





Quadrant orientation as viewed from End A to B.

Figure 2. Schematic of calibration and grading regions for the pipe with natural corrosion defects.



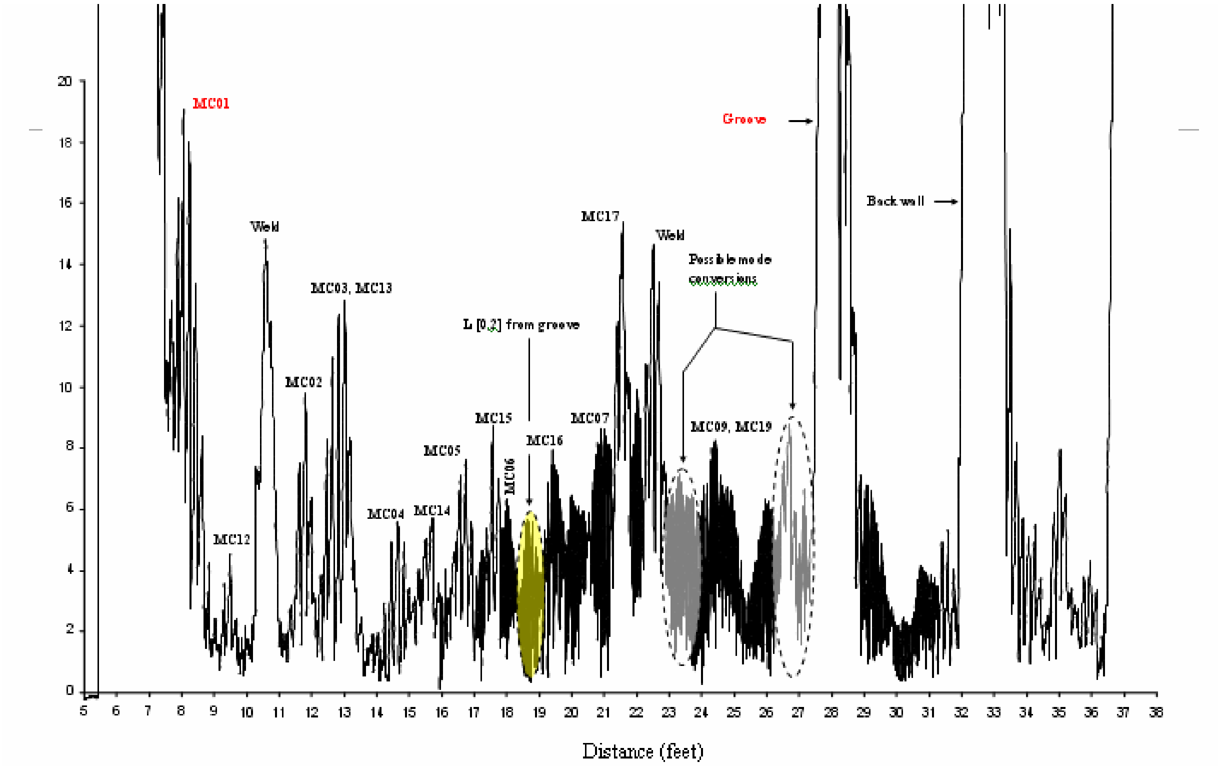


Figure3. Frequency scans of machined defects pipe showing responses from grading regions. Red indicates calibration regions.

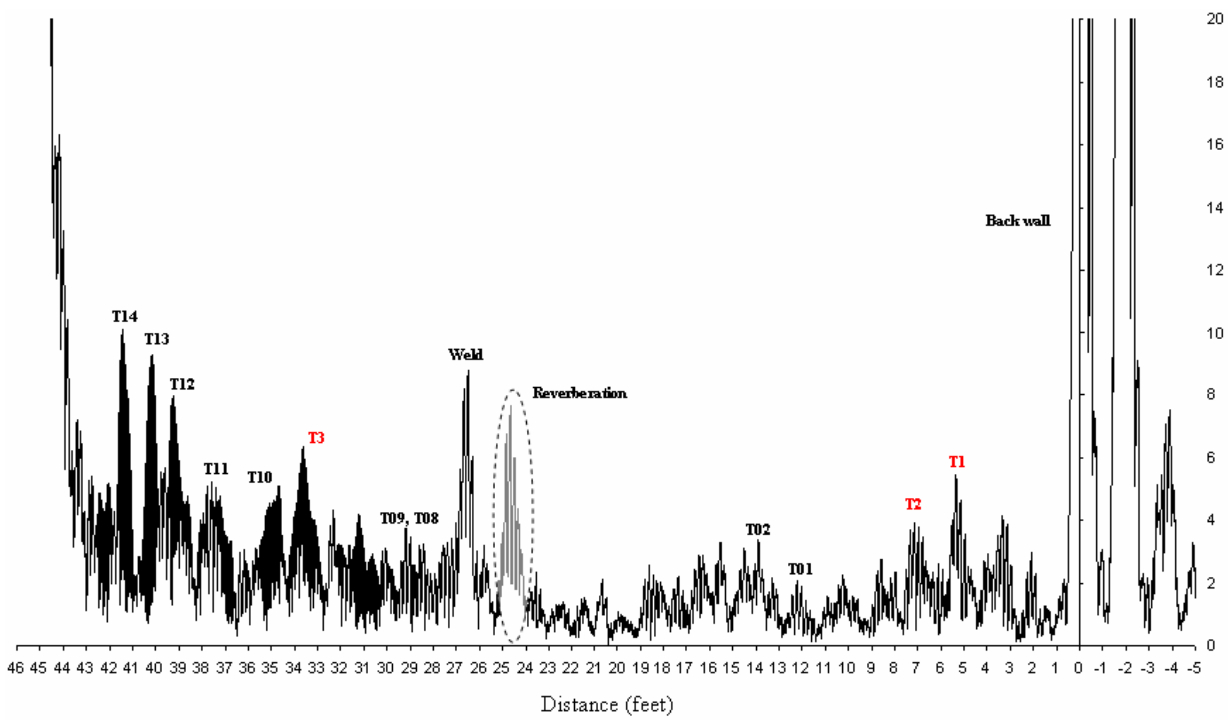


Figure 4. Frequency scan of natural corrosion defects pipe showing responses from grading regions. Red indicates calibration regions.

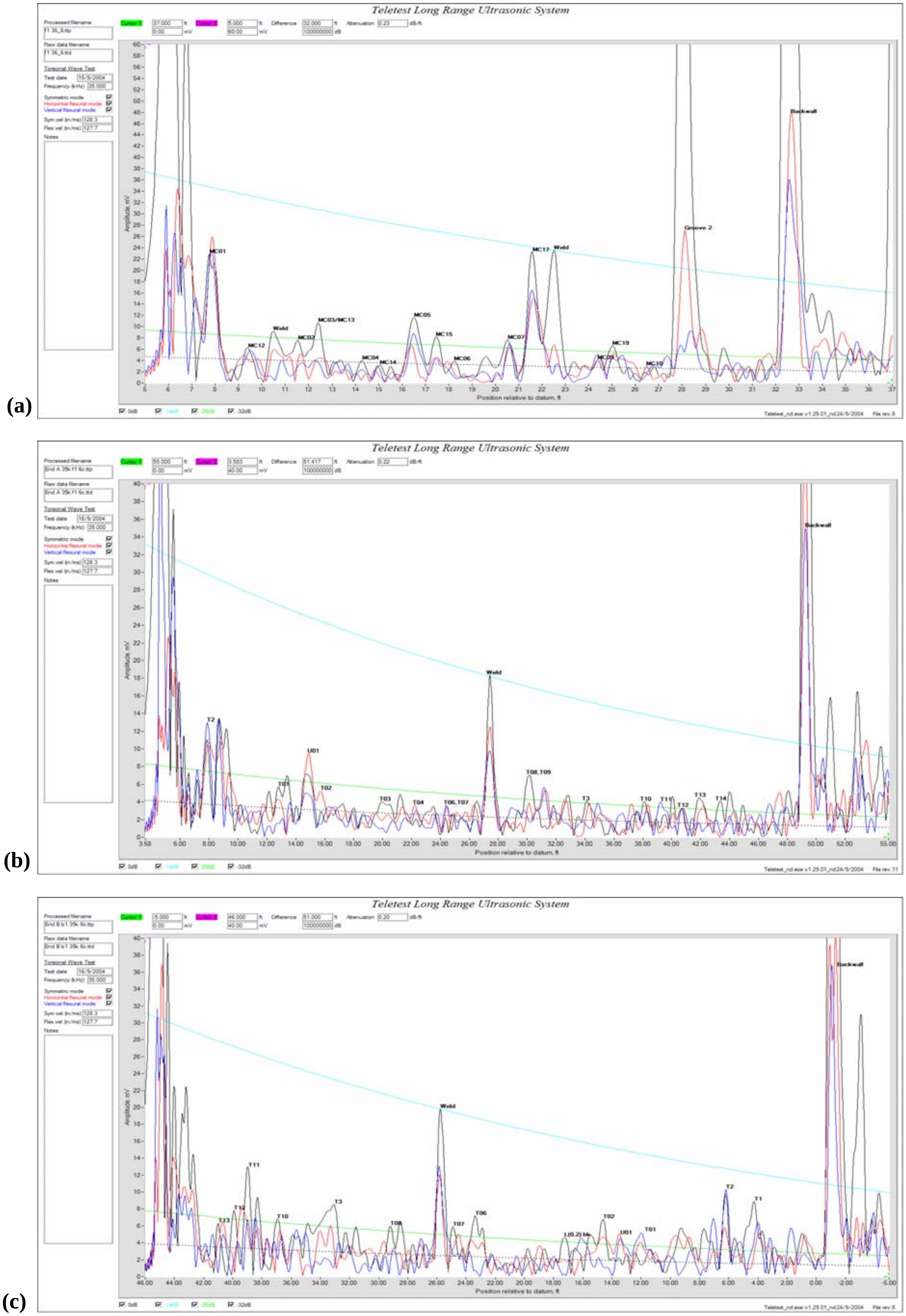
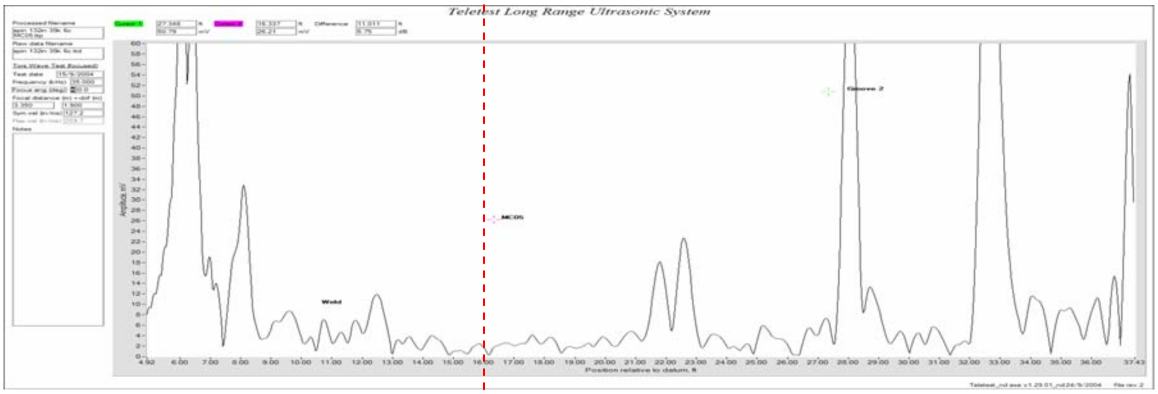
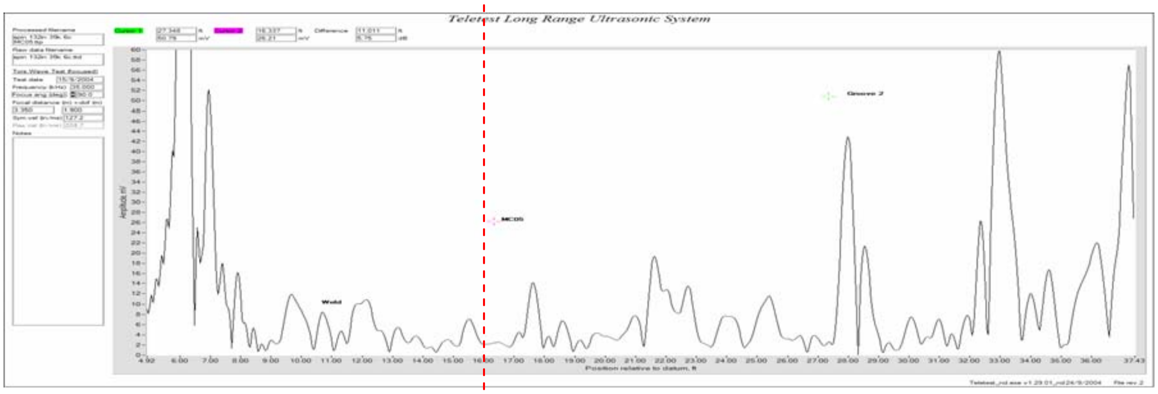


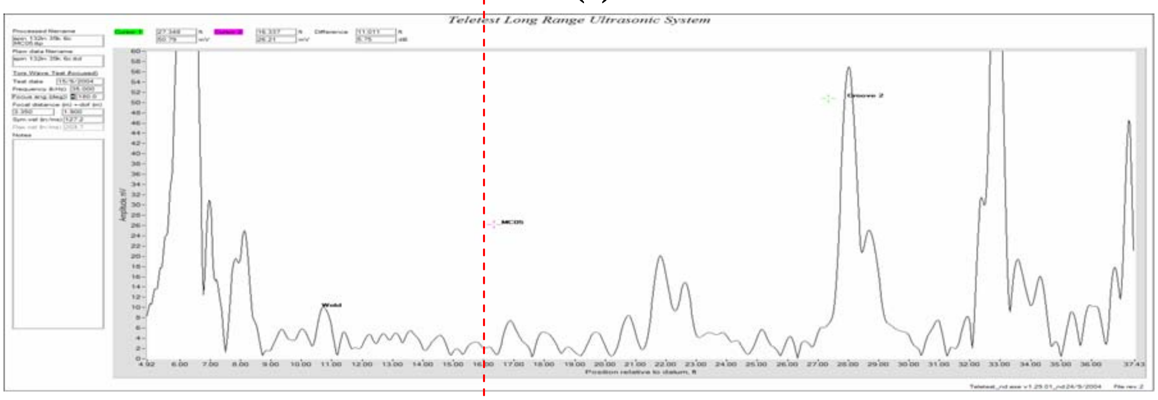
Figure 5. Axisymmetric responding signals from grading regions with transducers located at (a) 4.92’ from pipe end A of manufactured defect pipe, (b) 3.58’ and (c) 46.26’ from pipe end A of natural corrosion defect pipe.



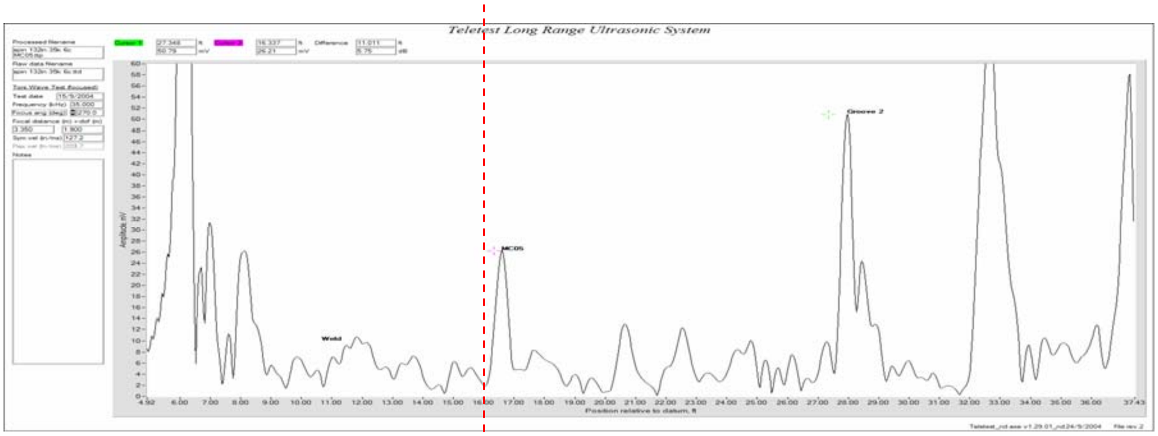
(a)



(b)



(c)



(d)

Figure 6. 35 kHz torsional responding signals excited at pipe end A of manufactured defect pipe when focusing at MC05 region at (a) 0º, (b) 90º, (c) 180º and (d) 270º. Red dash line indicates the expected location of the front edge of the MC05 signal.

Manufactured Defect Specimen Inspection Results

Table 1. Significant defects in the manufactured defect specimen

Inspection Area	Axial Location (From End A, ft)	Circumferential Location (º)	Approximate Size	Other Comments
MC01	7.3	270	Large	Calibration defect
MC05	16.1	270	Moderate	
MC15	17.0	90	Moderate	
MC07	20.1	270	Moderate	
MC17	21.1	90	Largest	

Table 2. Insignificant defects in the manufactured defect specimen

Inspection Area	Axial Location (From End A, ft)	Circumferential Location (º)	Approximate Size	Other Comments
MC12	9.0	90	Small	
MC02	11.1	All Quadrants	Small	
MC13,MC03	12.0	Q1, Q2, Q3	Small	
MC14	15.3	90	Tiny	(Not very clear)
MC06	17.9	90	Tiny	
MC09	23.8	270	Small	
MC19	24.6	All Quadrants	Small	

Table 3. Clean areas in the manufactured defect specimen

Inspection Area	Axial Location (From End A, ft)	Comments
MC11	8.5 - 9.5	
MC04	13.5 - 14.5	There might be a tiny defect located at 14.5 feet at 270 º.
MC16	18.5 - 19.5	There might be a tiny defect located at 19.1 feet at 270 º.
MC08	22.0 - 23.0	Too close to the second weld
MC18	22.67 - 23.67	Overlap with the mode conversion signals.
MC10	25.5 - 26.5	Overlap with the mode conversion signals.

*Q1: the quadrant from 45º to 135º (see Figure 2);
Q2: the quadrant from 135º to 225º (see Figure 2);
Q3: the quadrant from 225º to 315º (see Figure 2);
Q4: the quadrant from 315º to 45º (see Figure 2);

Natural Defect Specimen Inspection Results

Table 4. Significant defects in the natural defect specimen

Inspection Area	Axial Location (From End A, ft)	Circumferential Location*	Approximate Size	Other Comments
T2	7.5	Q2, Q3, and Q4	Manufactured defect at Q4: Small; Corrosions at Q2: Large	Calibration defects
T01	11.8 – 13.0	Q4 and Q1	Large	
U01**	14.0	Q2	Large	Out of the grading regions
T02	15.7 – 16.4	Q3 and Q4	Large	
T08	29.2	Q2 and Q4	Large	
T3	33.4	Q1 and Q4	Manufactured defect at Q4: Small; Corrosions at Q1: Large	Calibration defects
T11	39.2	Q1 and Q4	Large	
T12, T13	39.6 - 40.1	Q3 and Q4	Large	

Table 2. Insignificant defects in the natural defect specimen

Inspection Area	Axial Location (From End A, ft)	Circumferential Location (°)	Approximate Size	Other Comments
T03	18.7 – 20.0	Q1	Moderate	
T04	21.8	Q2	Moderate	
T06	24.0	Q2	Small	
T07	25.0	Q3 and Q4	Small	
T09	30.0	Q3 and Q4	Moderate	
T10	37.3	All quadrants	Moderate	
T14	41.8	All quadrants	Moderate	

Table 6. Clean areas in the natural defect specimen

Inspection Area	Axial Location (From End A, ft)	Comments
T05	22.67 – 23.67	No visible corrosion

*Q1: the quadrant from 45º to 135º (see Figure 2);
Q2: the quadrant from 135º to 225º (see Figure 2);
Q3: the quadrant from 225º to 315º (see Figure 2);
Q4: the quadrant from 315º to 45º (see Figure 2);

** Defect "U01" is not in the assigned regions, although we feel that it is too large to be ignored.

The results as shown in the above tables have been cast in the Battelle Excel format. The Excel formatted results follow.

Benchmarking of Inspection Technologies
Detection of Metal Loss - Page 1

Name:	Li Zhang
Date:	28-Sep-04
Company:	FBS, Inc.
Sensor Design:	TeleTest

CALIBRATION DATA

	Calibration Metal Loss Location	Metal Loss Length & Width	Depth of Metal Loss	Radius of Curvature	Measured Length & Width of Defect	Measured Depth of Defect	Comments
	inches from end A	inches	inches	inches			
Natural Corrosion Pipe Sample (48' 2")							
Calibration T1:	60"	1"	0.3"	0.557"			
Calibration T2:	96"	1.475"	0.21"	1.417"			
Calibration T3:	401"	1.475"	0.21"	1.417"			
Manufactured Metal Loss Pipe Sample (32')							
Groove Defect 1:	55"	0.5"	0.09"	0.25"			
Groove Defect 2:	329"	0.5"	0.14"	0.25"			
Calibration MC01:	90"	1.2" long x 3" wide	0.29	0.933			

TEST DATA

Pipe Sample: **Manufactured Corrosion Sample**

Defect Set: 12" Diameter, 0.358" Wall Thickness Pipe Sample with Manufactured Metal Loss

LINE 1

Defect Number	Search Region (Distance from End A)	Start of Metal Loss Region from Side A	End of Metal Loss Region from Side A	Total Length of Metal Loss Region	Width of Metal Loss Region	Maximum Depth of Metal Loss Region		Comments
	inches	inches	inches	inches	inches	inches		
MC02	126" to 138"	133						Small and present in all quadrants
MC03	144" to 156"	144						Small and present in quadrants 1, 2, and 3
MC04	162" to 174"	174						Very small; May be located at 270 degrees
MC05	186" to 198"	193						Moderate size at 270 degrees
MC06	210" to 222"	215						Very small located at 90 degrees
MC07	234" to 246"	241						Moderate size at 270 degrees
MC08	264" to 276"							No call; too close to a weld
MC09	282" to 294"	286						Small located at 270 degrees
MC10	306" to 318"							No call;Overlapped with mode converted signals

Benchmarking of Inspection Technologies
Detection of Metal Loss - Page 2

Name:	Li Zhang
Date:	28-Sep-04
Company:	FBS, Inc.
Sensor Design:	TeleTest

TEST DATA

Pipe Sample: **Manufactured Corrosion Sample**

Defect Set: 12" Diameter, 0.358" Wall Thickness Pipe Sample with Manufactured Metal Loss

LINE 2

Defect Number	Search Region (Distance from End A)	Start of Metal Loss Region from Side A	End of Metal Loss Region from Side A	Total Length of Metal Loss Region	Width of Metal Loss Region	Maximum Depth of Metal Loss Region		Comments
	inches	inches	inches	inches	inches	inches		
MC11	78" to 90"							No Call
MC12	102" to 114"	108						Small located at 90 degrees
MC13	138" to 150"	144						Small and present in quadrants 1, 2, and 3
MC14	174" to 186"	184						Very small and possibly at 90 degrees
MC15	198" to 210"	204						Moderate located 90 degrees
MC16	222" to 234"							Possibly a very small defect at 229 inches at 270 degrees
MC17	246" to 258"	253						Largest defect noted and located at 90 degrees
MC18	272" to 284"							No call;Overlapped with mode converted signals
MC19	288" to 300"	295						Small and present in all quadrants

Benchmarking of Inspection Technologies Detection of Metal Loss - Page 3								
Name:	Li Zhang							
Date:								28-Sep-04
Company:	FBS, Inc.							
Sensor Design:	TeleTest							
TEST DATA								
Pipe Sample:	**Natural Corrosion Sample**							
Defect Set:	12" Diameter, 0.31" to 0.38" Wall Thickness Pipe Sample with Natural Corrosion							
Defect Number	Search Region (Distance from End A)	Start of Metal Loss Region from Side A	End of Metal Loss Region from Side A	Total Length of Metal Loss Region	Width of Metal Loss Region	Maximum Depth of Metal Loss Region		Comments
	inches	inches	inches	inches	inches	inches		
T01	144" to 156"	142	156					Large located in quadrants 1 and 4
T02	180" to 192"	188	197					Large located in quadrants 3 and 4
T03	216" to 228"	224	240					Moderate located in quadrant 1
T04	260" to 272"	262						Moderate located in quadrant 2
T05	272" to 284"	272	284					No call
T06	284" to 296"	288						Small located in quadrant 2
T07	296" to 308"	300						Small located in quadrants 3 & 4
T08	348" to 360"	350						Large located in quadrants 2 & 4
T09	360" to 372"	360						Moderate located in quadrants 3 & 4
T10	438" to 450"	448						Moderate located in all quadrants
T11	462" to 474"	470						Large located in quadrants 1 & 4
T12	474" to 486"	475	481					Large located in quadrants 3 & 4 (with T13)
T13	486" to 498"	475	481					Large located in quadrants 3 & 4 (with T12)
T14	500" to 512"	502						Moderate located in all quadrants