Advances in Guided Wave Testing

by

Dr David Alleyne

About David Alleyne

- Personal mission is to innovate and develop Guided Wave NDT methods
- Developer and manufacturer of Guided Wave pipe screening and testing systems
- NOT a Guided Wave service provider, but a resource for support, training, and consultancy
- Imperial College researcher 1986-1998
- Operations Director and a founding member of GUL in 1998, which united world experts in guided waves
- Recognized world authority in the field of ultrasonic guided wave inspection and research methods with numerous papers and citations in the field

Outline

- Pipe Inspection motivation
- Overview of Guided Wave methods
- Guided Wave capabilities and improvements
- Examples from routine inspections
- Introduction to Guided wave monitoring
- Conclusions
- Questions

The problem

- Long lengths of pipe
- Restricted access
- Many un-pigable

- Regular NDT techniques (UT, RT…) not always appropriate. Very low coverage (normally <1%)

Coverage & regulatory requirements

Guided Wave Solution

- Guided Wave inspection offers:
- High productivity – 1000's feet per day
- Pipe access only required at transducer location
- Almost always carried out with pipe on-line
- 100% coverage possible
- Transparent procedure and audit control possible

Standard UT vs. Guided Waves

Standard UT	Guided Waves
high frequency	low frequency
short wavelength	long wavelength
sensitive to small defects at high frequencies	sensitive to "small" defects even at low frequencies
point measurement	rapid screening

The Essentials for using Guided Waves

1. Single mode generation
2. Control of direction
3. Separation of signals from symmetric and non-symmetric reflectors.

The latest systems requires all of the above to be controlled and reported for verification of the validity of the data

Typical Applications

- Pipe racks
- Vertical pipes
- Insulated pipe
- Pipe with restricted access
- Road crossings
- Submerged pipe
- Buried pipe

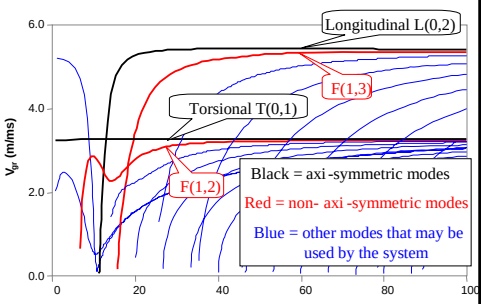
In widely differing climatic conditions

Technology growth and spread

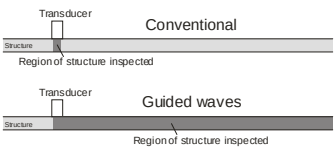
Currently there are over 200 guided wave systems performing routine inspections worldwide

About 100 inspection organizations from over 30 countries including, USA, China, Russia, Japan, UK, Australia, Mexico, France, Denmark, Norway, Saudi Arabia and South Africa.

Guided Waves in Pipes



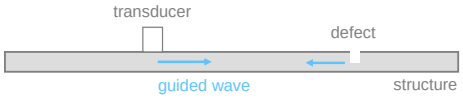
Propagation Along, Not Through, a Structure



The pipe walls form a guide for ultrasonic waves, which directs them down the length of the pipe

Guided Wave reflect from changes

- Guided waves travel along the pipe and are reflected from changes in the cross-section
- Amplitude of the reflection depends on the total change in the pipe wall cross-section



A brief summary of progress

- Application of Guided Waves in NDT started only 20-30 years ago
- Development at Imperial College started in 1987 Alleyne & Cawley
- First generation “field useable system” of technology licensed in 1997-1998
- GUL started in 1999 by the patent holders of the technology
- Second generation system 1999
- Third generation system 2005

Operational Differences Between the Modes

Torsional

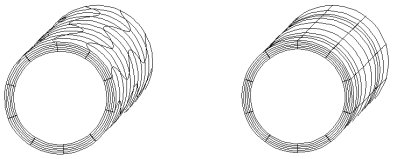
- Not sensitive to liquid contents
- Requires 2 rows of transducers
- Sensitive to deep axially oriented cracks as well as cross sectional area loss
- Can be used over a large frequency range
- Can be used with the rings very close to flanges
- Difficult to find corrosion at longitudinally welded supports on small pipes

Longitudinal

- Difficult to use on fully liquid filled pipes, inferior S/N ratio
- Requires 4 rows of transducers
- Purely sensitive to cross sectional area loss
- Can be used over only a limited frequency range
- The rings must be at least 1m from flanges or large reflectors
- Easier to find corrosion at longitudinally welded supports on small pipes

Primary Guided Waves Used

Symmetric guided wave modes used for interpretation



Symmetric (torsional)

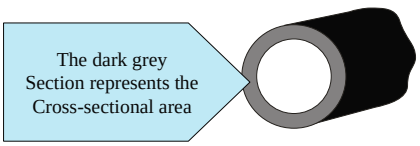
Symmetric (Longitudinal)

Complimentary nature of Guided Waves

- Guided Waves offer a unique inspection tool that can be utilized to maximum effect when used together with other NDT tools within an overall inspection philosophy.
- Guided Waves can be viewed as a critical screening and assessment tool within the “NDT toolbox” of capabilities

At every change in cross section there is a reflection of the guided waves

Amplitude depends on cross sectional area change

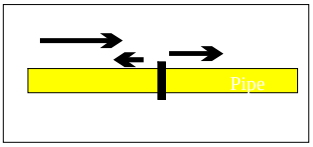


Change in cross-sectional area

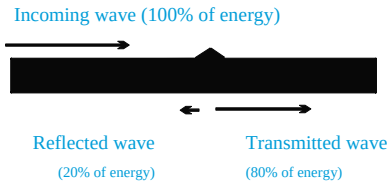
- Method is equally sensitive to defects at any though wall position
- Method is sensitive to changes in cross section (increase or decrease)
- Reflection from welds and flanges are used as a reference
- Amplitude of reflection is scaled with distance

Symmetric Reflections

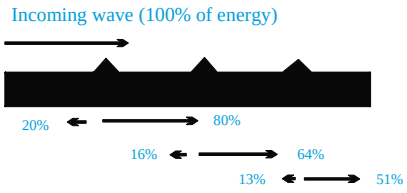
When they reflect from a symmetric feature (such as a weld), they are reflected as a symmetric wave which appears as a black trace



For example a weld

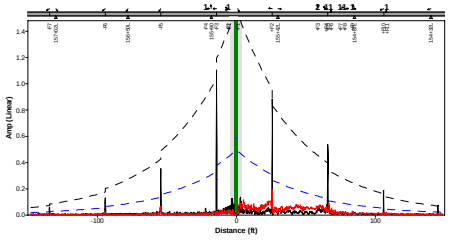


At each reflection the transmitted energy becomes less



These effects appear as an amplitude decay

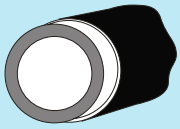
- The reflected amplitude from distant features will be smaller than for close features
- DAC curves are used to compensate for this



Wall loss geometry and Guided Waves

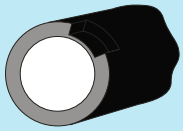
The percentage cross-section loss is given by the reflection amplitude, but it could be…

… equally distributed around the circumference (e.g. a shallow wall loss)



Symmetric Case

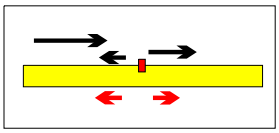
… concentrated in a narrow portion of the pipe (e.g. a critical deep defect)



Non-symmetric Case

Non-symmetric Reflectors

- When reflecting off non-symmetric features some non-symmetric waves are also created
- These appear as a red and black trace
- The amplitude of the red trace gives the degree of non symmetry



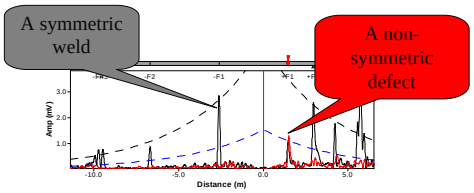
Symmetry Example

BLACK lines represent symmetric features

- Uniform around the circumference

RED lines represent non-symmetric features

- Varies around the circumference



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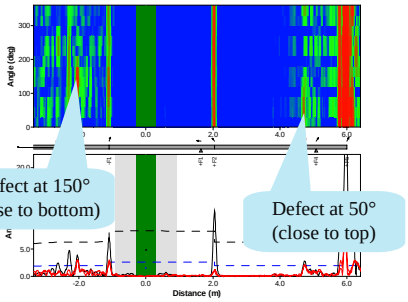
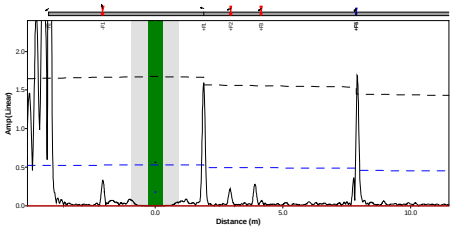
Unrolled Pipe Example



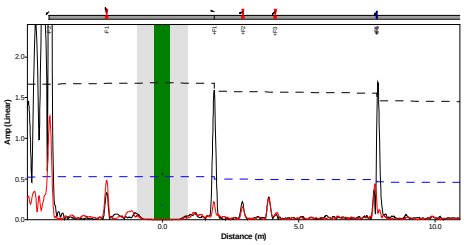
Guided Waves – 1st Generation

Typical A-scan type result showing torsional only



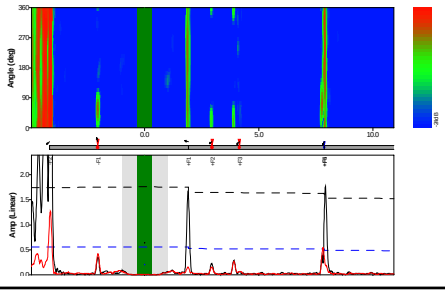
Guided Waves – 2nd Generation

Typical A-scan type result showing torsional and flexural response (note defect in weld)



Guided Waves – 3rd Generation

Unrolled (focused) pipe view above the A-scan. The C-Scan shows the axial and circumferential position and distribution of defects and features.



Determining Wall Thickness Reduction

- The remaining wall thickness is never measured directly using guided waves, which is why it is considered as a screening and classification tool
- It is normal (best) practice to determine accurate defect dimensions using a complementary method such as UT thickness measurement

Pipe Diameters

- Pipes up to 72 inches in diameter have been inspected
- Pipes down to ¾ inch (19mm) can be inspected using special rings

Detection Threshold

- A typically detection threshold setting is 3-7% cross sectional loss
- If pipe is mostly in good general condition defects down to less than 1% have been detected
- A 1% defect in a 3" pipe equates to a half wall defect 0.2" diameter *
- The detection threshold should be set as high as practical for the required reliability?*

**** Please note real corrosion is not and does not behave like flat bottom holes or machined notches***

Diagnostic Range

- In ideal conditions >500 ft of pipe can be screened in each direction from a single test location
- Typically range on above ground pipe is varied but 70-130 ft in each direction is realistic *
- For buried pipes <70ft in each direction is more typical unless the pipe is sleeved
- Please note range, sensitivity and missed or false call rates are related so a compromise is normal

**** Assuming no severe corrosion and/or large pipe features***

Unrolled Pipe "C-Scan"

- Circumferential orientation can be accurately determined
- Works best with newly developed multi-channel rings
- Gives information in an equivalent format as, for example, in-line inspection tools
- Reduces interpretation effort and time and in most cases increases accuracy of calls
- Critical for improvements at finding defects/corrosion at bends, supports and other welded features

Limiting Factors

- General condition of pipe has a significant influence on the detection threshold and range
- Many coatings and coverings (for example earth) reduce range
- High external noise, such as compressors, reduce performance
- Operator competence

Effect of Pipe Contents

Gases - no effect

Liquids

- No effect when low viscosity

Sludge

- Heavy viscous deposits in the pipe attenuate the signal and reduce the test range

Reporting is critical

- Reporting features designed to increase productivity and accuracy
- All raw data stored for later review and auditing (this can not be altered)
- Reports can be printed directly or imported into other applications
- Photographs can be embedded in the report file
- GPS positions can be incorporated to map and record coverage

** Guided Wave based tool is evolving into pipeline assessment and integrity system*

Examples

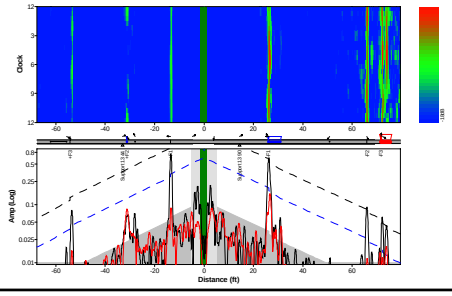
All the results presented were obtained from client inspection companies and were taken during routine inspections by trained operators

Typical capabilities of advanced system

- Self contained internal battery for flexible site working
- Automatic pipe size detection and test sequence setup
- Automatic data collection over all valid frequency ranges
- Large pipe diameter and thickness range (typically from 3/4" to 72").
- Focusing (at any position within range)
- Operator recognition & procedure control

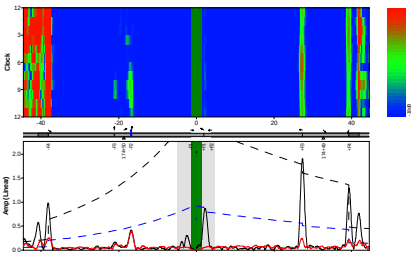
Unrolled (Focused) Pipe View

There are small isolated corrosion sites and generalized corrosion axially and circumferentially distributed over a few feet. All corrosion was verified after removal of insulation

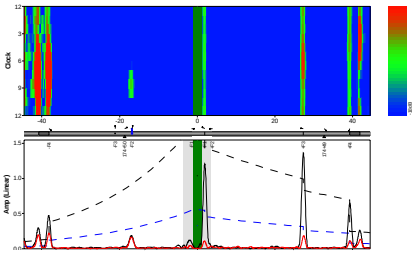


Frequency example

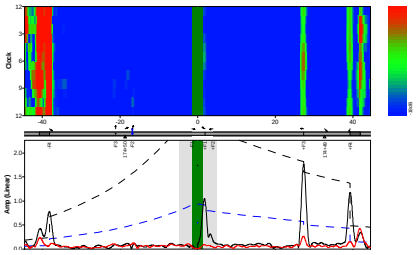
Isolated c



Frequency example

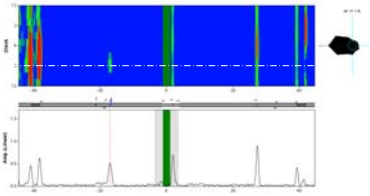


Frequency example



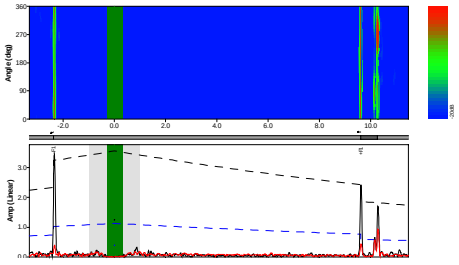
Frequency example: Focusing

Focused A-Scan at ALL axial positions at the 9 o clock angle (as shown by the white dashed line.

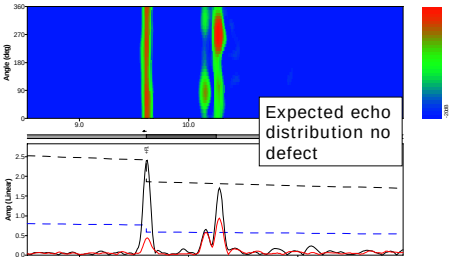


Signature from bend welds

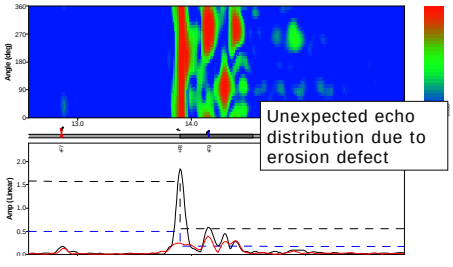
Bend signature for an 8inch standard fitting



Zoomed-in view of bend echoes



Zoomed-in view of bend echoes

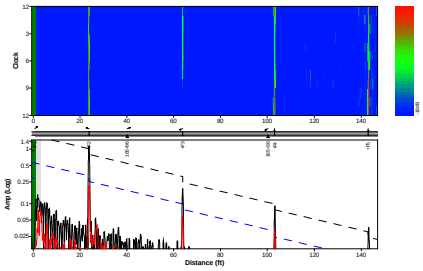


Productivity

1. Long length of pipe
2. CUI a potential problem
3. Currently many miles completed by crews of 2 persons
4. Productivity potentially 1000's feet per day, per crew
5. Screening and follow-up can be complimentary
6. Pipeline operation not normally compromised

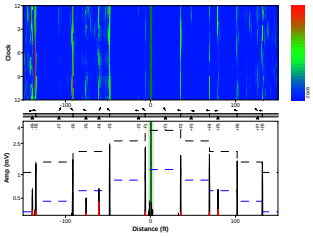
Productivity example

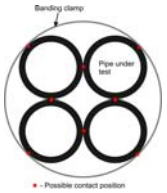
Test range > 145ft in each direction



Inspection of bundled pipes

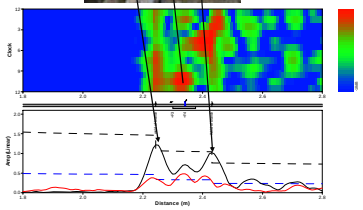
C-Scan required to determine between defects and supports





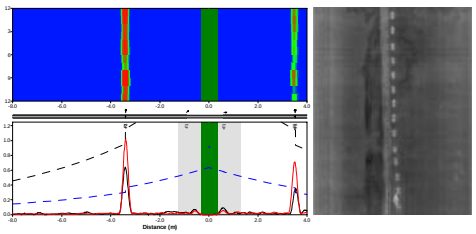
Detection of defects at a Tee: C-Scan

The signal at the 12 o clock position is from the defect



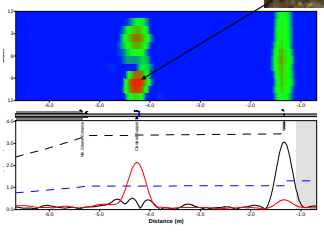
Corrosion at welds 24" diameter Pipe

Corrosion at weld locations & RT confirmation, the location of the corrosion around the circumference matches that shown in the C-Scan



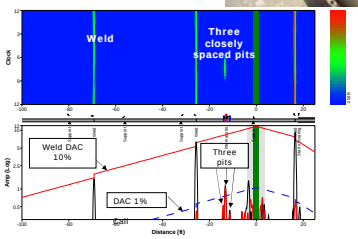
Corrosion at clamp support: C-Scan

The position of the corrosion matches the location displayed in the C-Scan



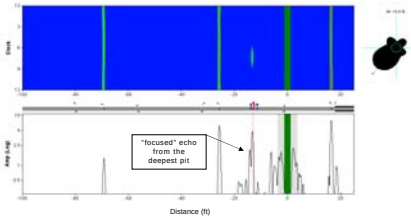
Super Sensitivity

Very small internal pits <1%ECL



Super Sensitivity enhanced by focusing

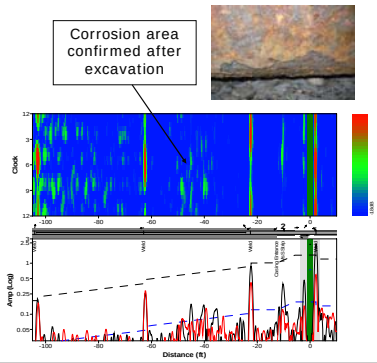
The amplitude of the echo from the pits are larger (relative to the weld echoes)



Cased Road Crossings

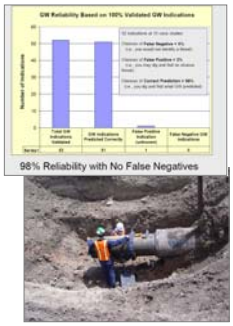
- Road crossings and insulated pipe inspected
- Wavemaker G3 technology now accepted

Result from cased road crossing



Inaccessible buried pipe

- Trial carried out by Gas Technology Institute (GTI)
- 15 sites tested and results compared to MFL pig and direct assessment



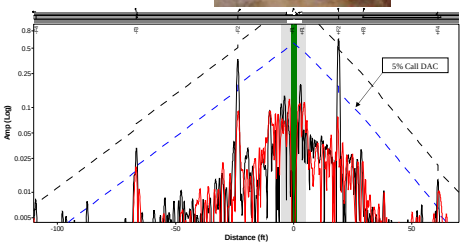
Case Study: Inaccessible pipe

GTI report concluded:

Wavemaker Technology developed by Guided Ultrasonics has been successfully implemented in the USA Gas industry by the Gas Technology Institute

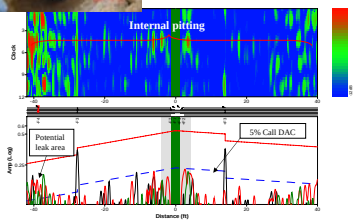
The results suggest that Guided Waves can be used for screening of road crossings and buried lines provided that the technology is implemented correctly

Buried pipe

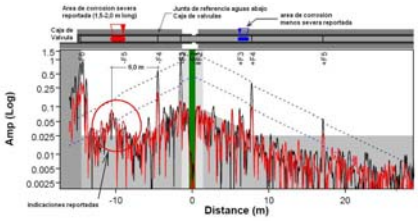


Buried pipe with internal pitting

Severe pitting at about -40ft



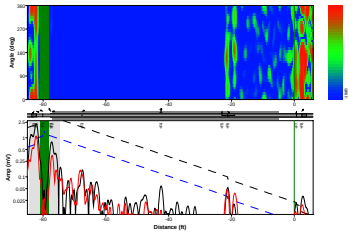
Buried Pipe with external corrosion



Advanced Testing Configurations

- Pulse-Echo - default testing configuration
- Pitch-Catch - configuration for improved S/N…;
- Through Transmission - configuration for attenuation measure…;

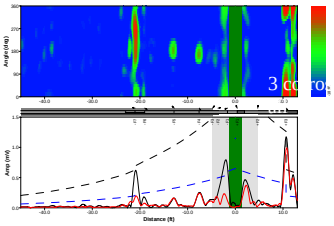
Pitch-Catch: Torsional



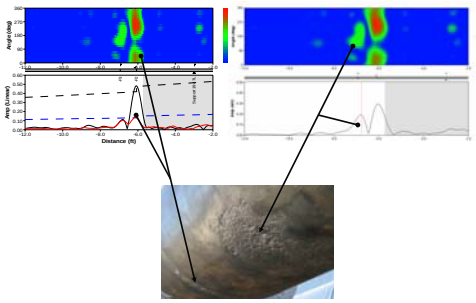
Road crossing test in which the S/N was improved with pitch-catch so the full length of the crossing could be inspected from each side

Improved Classification “Sizing”

- Using Enhanced Focusing Rings and Fr slider
- Blind trial: Corrosion sized & positioned correctly



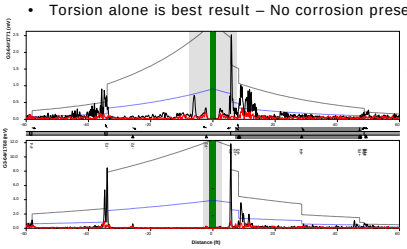
High Sensitivity, Fr and Focusing



Pitch-Catch: Torsion Longitudinal

Comparison of results from modes

- Result from Cased road crossing pipe.
- Optimum transducer set-up 4-row Longitudinal; 2-row Torsional.
- Torsion alone is best result – No corrosion present



L(0,2)

T(0,1)

Guided Wave Monitoring - PIMS

PIMS is a transducer ring (**P**ermanent **I**nspection **M**onitoring **S**ystem) attached to the pipe under interrogation.

- Provides a simple means of repeating guided wave inspection of a pipeline over an extended period of time.
- Sealed in a polyurethane mould to give lifetime protection.

Motivation for PIMS

- The time and cost incurred in the inspection of many pipelines is dominated by the access costs.
- The installation of PIMS means that this only needs to be done once.
- Repeat testing is then a simple matter of attaching transducer cables at a conveniently placed location and retesting.

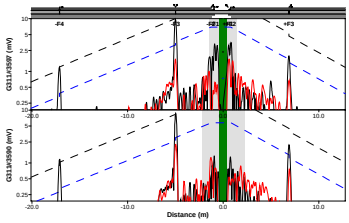
PIMS Features

- Standard weather proof box is uniquely serial numbered
- Programmed with all test parameters during installation
- Custom connectors can be used such as for sub sea use
- Re-testing is a simple plug in and collect

PIMS Buried Pipe Performance

Performance matches that of conventional transducer rings with all the options available

Result from buried 8” line



Result usi
PIMS (bef
back-fill)

Result usi
standard

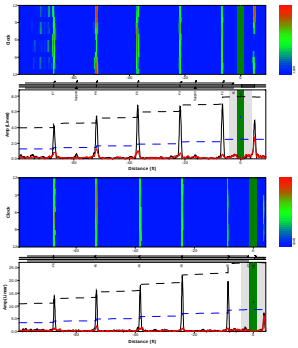
PIMS Example Application

- 24" buried line in tank farm
- **PIMS** installed on buried section beneath instrument
- Connection box on yellow post

Cased Road Crossing pipes

PIMS installed on pipes at a cased road crossing position prior to back filling. Monitoring tests can be performed without expensive excavations in the future.

PIMS Results from 2 cased pipes



Ø12", Pipe 146

Ø14", Pipe 140

Considerations when using Guided Waves

- Equipment - capability of the system
- Operator - Training & certification (ongoing)
- Procedures - within the system and company

* ***The above (and the data S/N ratio) largely determine the POD for Guided wave testing***

Training & certification

Reputation of the method is linked to operator competence

- **Comprehensive operator training:** trained by experts in the guided wave method (with practical site experience)
- **Training Scheme:** adoption similar to PCN, which is a recognized industry standard
- **Qualification Levels:** 3 levels of qualifications are recommended according to the difficulty of applications
- **Revalidation scheme:** to ensure only operators with valid up-to-date training are on the job.
- **Training simulation:** added protection to the end clients

Certification

Auditable information via electronic operator i-buttons:

- Record of certification status
- Used to log-on to instruments each day
- Number of days/tests performed
- Respected certification is desirable and valued
- Can be used with procedures

Procedures

They should specify all aspects of the work including, for example:

- Certification requirements
- Collection and interpretation protocols
- Call and classification levels
- Data quality and S/N requirements
- Defects and/or areas of interest
- Climatic, operational or other testing limitations
- Audit, reporting and verification requirements
- Areas of the pipeline not covered

Conclusions

- Over 200 guided wave systems working world wide
- Technology developing rapidly
- Newly introduced techniques can be employed to find very small changes in cross section
- Dynamic frequency slider capability increases sensitivity by order of magnitude in many applications
- Focusing and C-Scan also increases sensitivity and defect "sizing" capability
- Monitoring is gaining more importance
- Dead-zone extent and limitations at welded fitting are important
- The shape and geometry of "real" corrosion influences reflectance (so detection capability). The amplitude of echoes from corrosion may be different from each direction
- Performance differences large because of equipment, procedures and operators
- Operator training and interpretation expertise critical

Questions please

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