Is it Ultrasonic or is it Radiography inspection?

(Case Study- Difficult Pipe weld comparing AUT to RT)

Title **Is it Ultrasonic or is it Radiography inspection?**

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Paper delivered at the 2005 National Pressure Equipment Conference, February 2005, Banff, Alberta, Canada

Abstract

Risk is always part of the engineering effort and change as we progress though the life cycle of a project, from design to construction to in service and eventual phased-out. The risk engineering effort of the one phase has a direct influence on the next phase of the project. This paper report on an investigation of the risk associated with the welding of a 600mm steamline using a new material for this application, and a welding procedure with out post weld heat treatment. The quality aspects of the risks were investigated and the using of both radiography and automated ultrasonic testing to verify the weld quality. Can we inspect the weld by only Radiography or only AUT (TOFD)? Or do you need both?
TOFD - Time Of Flight Diffraction Technique an alternative to Radiography

<u>Experts</u>

"He who does not know
And does not know
That he does not know
Is a fool – avoid him" Richard Burton

"An expert is someone who knows
Some of the worst mistakes
That can be made in his subject
And how to avoid them." Heisenberg

1 Introduction

This paper report on an investigation of the risk mitigation associated with the welding of a 600mm x 25mm steam pipeline using a new material for this application, and difficult weld procedure under harsh environmental conditions, the winter in the northern part of Alberta, Canada.

The quality requirements implemented to reduce the potential of weld failure were investigated. The requirement for 100% radiographic inspection and 100% automated ultrasonic testing (TOFD) to verify the weld quality is questioned. Is this an over kill or can we use the one in lieu of the other.

The question was asked by contractors and inspectors why both? And if we do find a defect by RT and not by UT do we really have to do something. The objective of this paper is to provide an answer to this question – Can we use only AUT (TOFD) or only radiography as an inspection technique for this size of welds?

This paper is not giving details on the actual AUT (TOFD) and radiography techniques used for the inspection of the welding, the focus is on the outcome of the inspection and the comparison of the detection of possible weld imperfections in the weld.

2 Risk Engineering

2.1 Risk concepts and definitions

Risk – how do we define this concept:

» Definition: Risk is an event that threatens the accomplishment of one or more future goals or objectives.

» A Risk is described by the likelihood that an event will occur and the severity of the consequence of that event should it occur.

» Risk is about a possible future event and is often confused with issues and problems. If the likelihood is certain or near certain, then it is not a risk.
(ref: INCOSE)

Risk Assessment (about "a" risk):

- The process of estimating the probability and impact for each risk.

Risk Assessment tries to answer the following questions:

- What can happen?

- How likely is it to happen?
- Given that it occurs what are the consequences?

2.2 Why Risk Engineering?

Risk has always been an inherent part of the every day life. People accept risk because they want to achieve their goals.
The evolution of mankind increases the importance of risk management in the industry. It is also evident in the CSA Oil and Gas Pipeline Systems code, Z662-03.
Structural design used to follow deterministic approach i.e. minimum material properties and specified load intensities. This is also the philosophy of most structural and pressure equipment design codes. If we start to follow a risk engineering approach the philosophy change to the situation where the design engineer has to recognize that some risk of unacceptable structural performance must be tolerated. This allows for the application of fracture mechanics and the determination of minimum acceptable flaw sizes in a structure. The objective of the design engineer is ensuring that the probability of failure will be at an unacceptable level.

The service and design conditions of systems are of a complex nature and therefore it is important to identify the contributing factors to structural uncertainties.
The aim should be to identify the various uncertainties associated with the structure and to investigate their interaction and contribution to overall reliability of the structure.

Risk assessment should be considered as an integral part of the design of structures to achieve structural integrity.

Risk is also important as a base for management decisions on inspection, maintenance, and investigation of the life cycle of engineering structures and equipment.

In engineering projects the criteria used for risk is the estimation of the time to failure, or probability of failure. It is possible to connect the probability of occurrence to the consequence of failure. In specifications and codes such as API 581 and CSA Z662 risk is determined as a product of probability of occurrence (failure) POF, and consequence of occurrence (failure) of an undesirable event,

RISK LEVEL = PROBABILITY OF FAILURE x CONSEQUENCE

This paper investigates an aspect of the probability of failure – to take all precautions in our design and verification techniques to minimize the probability of a failure.

Structural Integrity depends on the identification of potential structural failure modes and a design to minimise potential failure. It also has to measure the potential for failure and control it.

Risk Engineering is the war against unexpected failures.
The formal risk engineering process use techniques such as FMEA, to understand why a failure may occur.
"Failure spreads across all the various engineering fields – engineering products are only successful to the extend that their designers properly anticipated how a product can fail to perform as intended (ref. J X Wong e M L Rauch – Risk Engineering and Management, Marcel Dekker, New York).

The FMEA gave us the answer to the question "How can this product fail?"

One failure mode identified for the steam pipeline was that of a weld failure – the harbouring of an unacceptable large defect in the weld that may lead to a catastrophic failure.

2.3 Are the structure/welds at risk? Not if we manage it!

There is considerable experience in pressure equipment fabrication and pipeline construction in Alberta. Is there a real concern? No, only if it is allowed that the expected quality of workmanship assumed by the designer is not maintained during construction. Poor quality engineering will increase the probability of a weld failure (Structural Failure). The engineer has to manage risk through out the project life cycle.

Risk Management:

Definition: Risk management is the formal process of identifying risks, assessing their magnitude, making decisions about how to handle, and then tracking the progress of the handling approach.

Risk Engineering is based on sound principals but also on **sound data.**

2.4 The Risk of doing risk assessment

Performing a Risks assessment may have some typical pitfalls that have to be avoided:

- Not considering all factors.
- Underestimating human factors.
- Not considering the system as a whole.
- Overconfidence in judgements.

- Inaccurate estimates.

2.5 Types of Risk Assessment

Types of Risk Assessment	
Quantitative	**Qualitative**
Scientific studies & measurements	Semi-scientific or non scientific
Comparison of results with limit values	Judgement decisions
Occupational Hygiene, Noise, Structural Design, Ergonomics	Professional and personal experience biases
	Codes of Practise

FMEA is a qualitative analysis of risk.

It is also possible to do a more quantitative analysis as part of the risk assessment.

2.6 Actions that mat be taken as part of risk assessment:

To determine the occurrence, severity and detection ranking of the risk.

- **Occurrence**, the mitigation of a moderate risk to a lower probability of occurrence. [O]

- Assess the **severity** of failure – what may happen if a failure do occur – how serious is the failure. [S]

- The change of severity is under the full control of the design engineer.

- **Detection –** do we know the quality level of the system (i.e. weld). How can we identify the possible failure of the welds? [D]

- Detect possible defects before it can cause a catastrophic failure.

The probability of failure P = S* O * D
(ref. Risk Engineering and Management, Wong John X, Roush Marvin L)

2.7 Statement on the norms of risk assessment

Bushy: Designers' risk assessment provides a starting point for constructors' risk assessment, and so on down the process, although presumably this introduces the 'second- opinion' effect (Fischoff)

2.8 Summary of risk assessment

2.8.1 Risk Assessment – simple approach

The five simple steps to do a qualitative risk assessment of general equipment (starting point) are:

Step 1: Look for the hazards.
Step 2: Decide who might be harmed and how.
Step 3: Evaluate the risks and decide whether the existing precautions are adequate or whether more should be done.
Step 4: Record your findings.
Step 5: Review your assessment and revise it if necessary.

The case study will be done looking at step 3 and 4. Evaluate the weld quality, taking steps to reduce the probability of failure and record the out come of the inspections.

2.8.2 Risk Assessment: A Qualitative and Quantitative Approach

Various organizations have different approaches to safety in the operation of plant and equipment. The recommendations are divided into three sections.

The analytical approach relies on statistically based failures, with the failure rates of each component being obtained from data banks. The numerical data are then processed from the first input and proceeding, through the functional block diagram, using mathematical relationships.

A study done by J B Wintle a.o. at TWI, in 2001 concludes that ‘Quantitative risk analysis has not yet reached the stage of development where it can be used indiscriminately to appraise risks associated with the process industries. Work should continue on the improvement of both methods used and the data bases required for risk analysis, because it is a potentially useful tool for assisting with safety decision making.’

The case study aim to improve the quantitative information on the weld by not only doing NDE but also comparing the probability of detection of possible failure.

3 Case Study – 600 mm Steam pipeline

3.1 Background

The aim of this paper is to present the strategies to analyze only one aspect in the risk assessment of a pipeline and to investigate the perception of inspection techniques used to reduce the risk of future failure of a structure, or alternatively improving the potential integrity of the structure. This is a quantitative approach to risk assessment.

The client had a requirement to construct a 600-mm diameter steam pipeline in northern Alberta, Canada. Engineering consultants engineered the pipeline and RAE Engineering was requested by the client to investigate the welding quality and to propose a weld quality program to ensure a high structural integrity.

The steam pipeline is defined as follows:

- 24 " Steam pipeline, CSA Z245.1 grade 550 Cat II pipe material with 25mm wall thickness will be used, total length about 9500m in the first phase and about 6000m in the second phase.

- The pipeline design and construction will be in accordance with CSA Z 662-99, Oil and Gas pipelines specification.
- The pipeline will be above ground and will be cladded.

This pipeline posed a few risks that were identified early in the project life cycle.

The potential risks identified were as follows (step 1)

- Above ground cladded pipeline.
- Weld of 25mm wall thickness, 600mm diameter during winter conditions (down to –30C).
- Materials to be Z245.1 grade 550 category II.
- Welding process is difficult.
- Residual stress levels at the welds may be high.
- Difficulty to set-up pipe for welding
- Difficult to identify possible future failures underneath cladding.
- No post weld heat treatment.
- Possibility of delayed weld cracking.
- Maintaining acceptable material toughness.

4 Mitigation Actions

The following actions were proposed to reduce the level of the potential weld risk (step 4):

- WPS required high temperature impact testing – ensure weld toughness.
- Establish hardness criteria.
- Qualification of welders using an actual mock-up and simulated field conditions.
- The possible high weld hardness – monitor hardness.
- Delayed cracking – check for cracks after welding and after a 48 hour time delay.
- Identify with the highest possible probability all weld defects that can cause possible future failure.

5 The Quality Verification Strategy

To further reduce the potential risk (continuous mitigation as part of step 3) in not achieving a good quality weld a quality plan was defined that included the following strategy:

- All welders to be tested on site under construction conditions.
- No deviation from defined and tested weld procedure.
- Ensure use of dry ovens and hot boxes with minimum number of welding rods issued at all times.
- Controlled issue of welding rods
- Continuous monitoring of pre-heat and heat input during welding. Two welders would be used to weld simultaneously starting at 6 o clock position welding up to 12 o clock position.
- Controlled blanket cooling of welds.
- 100% Visual inspections, radiographic and automated ultrasonic testing (TOFD). The AUT was delayed by 48 hours to detect possible delayed cracking.
- Using independent contractors to do RT and AUT (TOFD)
- Check the hardness of the completed weld, shall not axceed 260 hardness Vickers.
- Document the weld procedure and NDE procedures used
- Do fracture toughness tests (CTOD) of welds to verify K_{IC} values. This gave actual values that were used to calculate the critical crack length and verify leak before failure.
- Include high temperature material impact test (Charpy) as a requirement for the weld qualification to ensure material toughness.
- Use low hydrogen weld material

- Controlled preheat and interpass temperatures. Post weld cooling rate was controlled.

6 Comparison of the weld quality by radiography and automated ultrasonic testing

6.1 Radiography

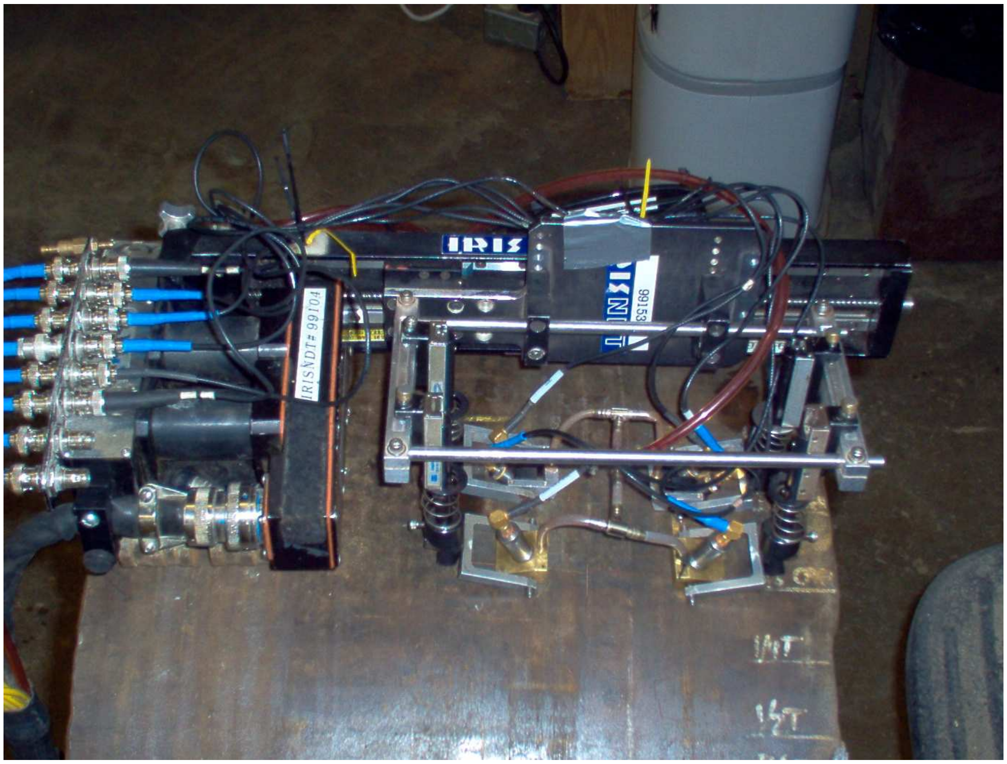
The requirement defined radiography as the first inspection of the weld as soon as possible after completion of the cooling. A 100% radiographic examination was done. Repairs were done if defects were identified to be outside B31.3 acceptance criteria.

6.2 The TOFD or Automated Ultrasonic Testing (AUT)

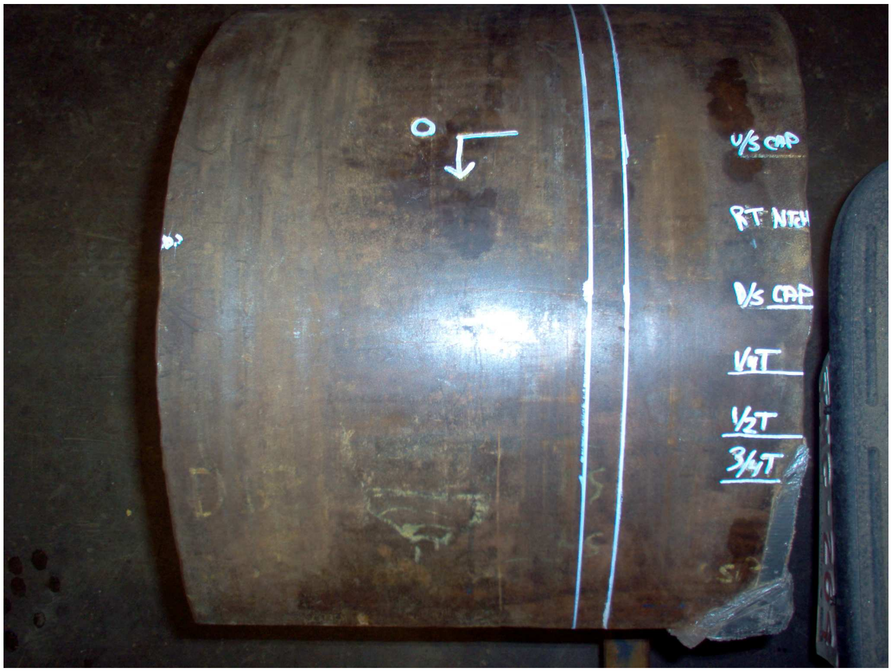
Although radiography (RT) is still the leading method for volumetric weld inspection it is realized that AUT, apart from the fact that it avoids radiation hazards and chemical waste, can lead be an alternative inspection method (see ASME Code case 2235). This tendency has been even more stimulated by the introduction of the Time of Flight Diffraction (TOFD) technique, as a powerful ultrasonic inspection technique with the availability of a permanent record of the weld inspected.

The steam pipeline application used the following set-up: a TOFD transducer set and focused 45-degree shear wave transducers at the opposite edge of the weld cap to cover the top blind zone was used. A 60-degree transducers at the root covered the back wall blind zone. The shear wave channels use 6mm, 5 MHz transducers that are calibrated to the notches.

See the following figure.



The Scanner and probe array set-up at the weld



The calibration block top side

The calibration block was a test specimen used previously, an actual pipe section with slots machined to simulate different sizes of defects.

The Calibration block bottom side

The following figures show typical output from the AUT (TOFD) inspections.

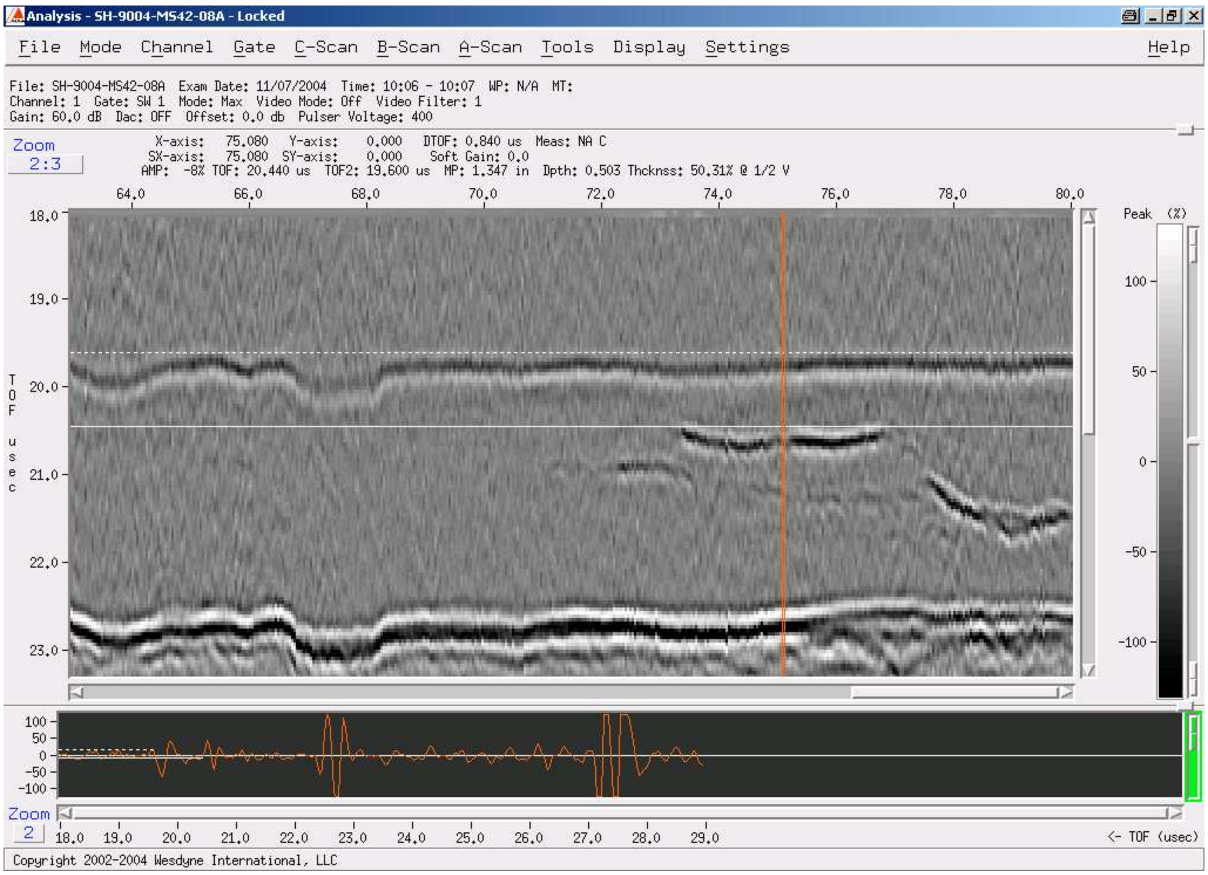


Image of Slag – Cursor denotes depth of top indication

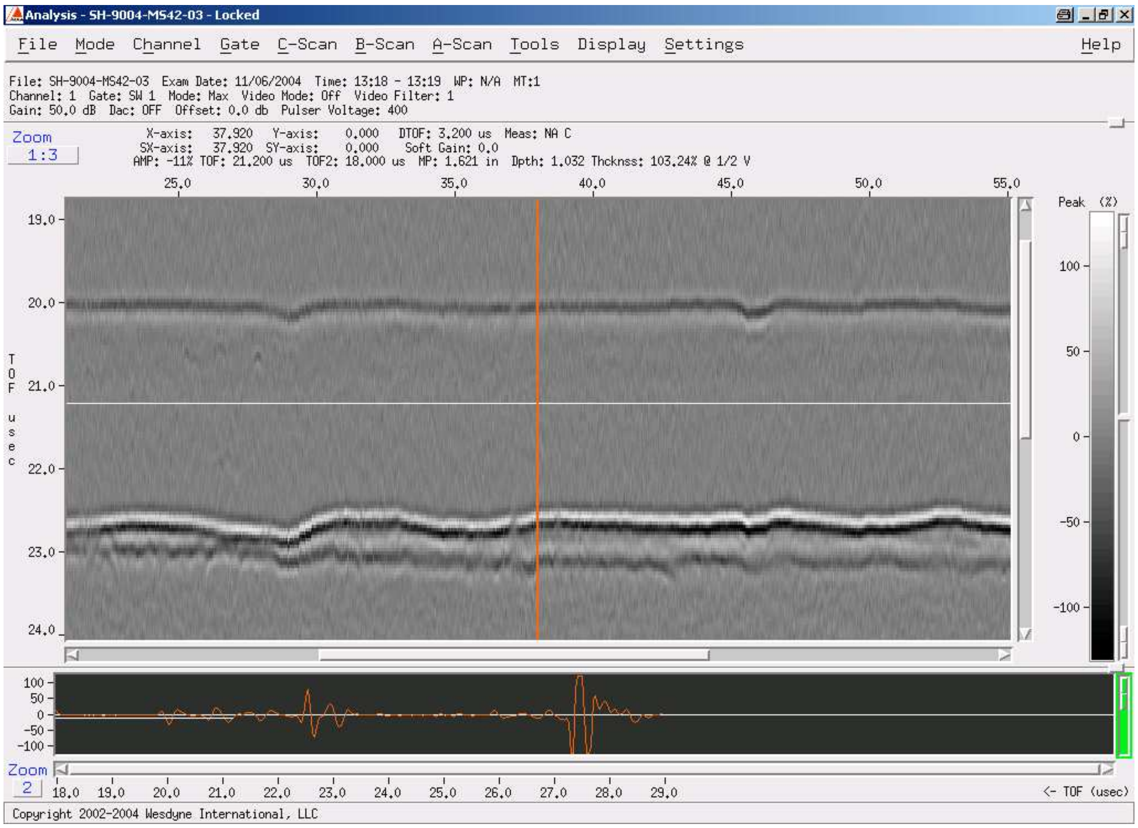


Image of a weld with no discontinuities

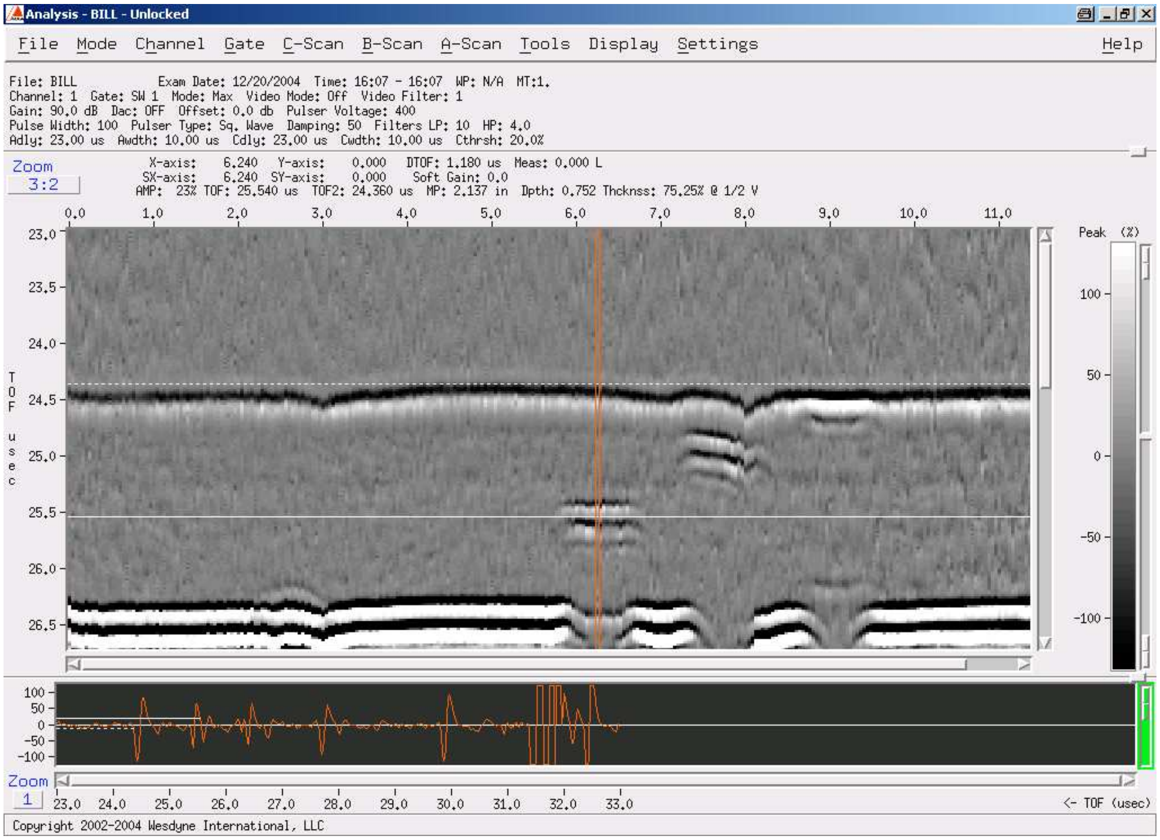


Image of Calibration Block – Sized to the ¾ T Notch (Plate Thick 1.000")

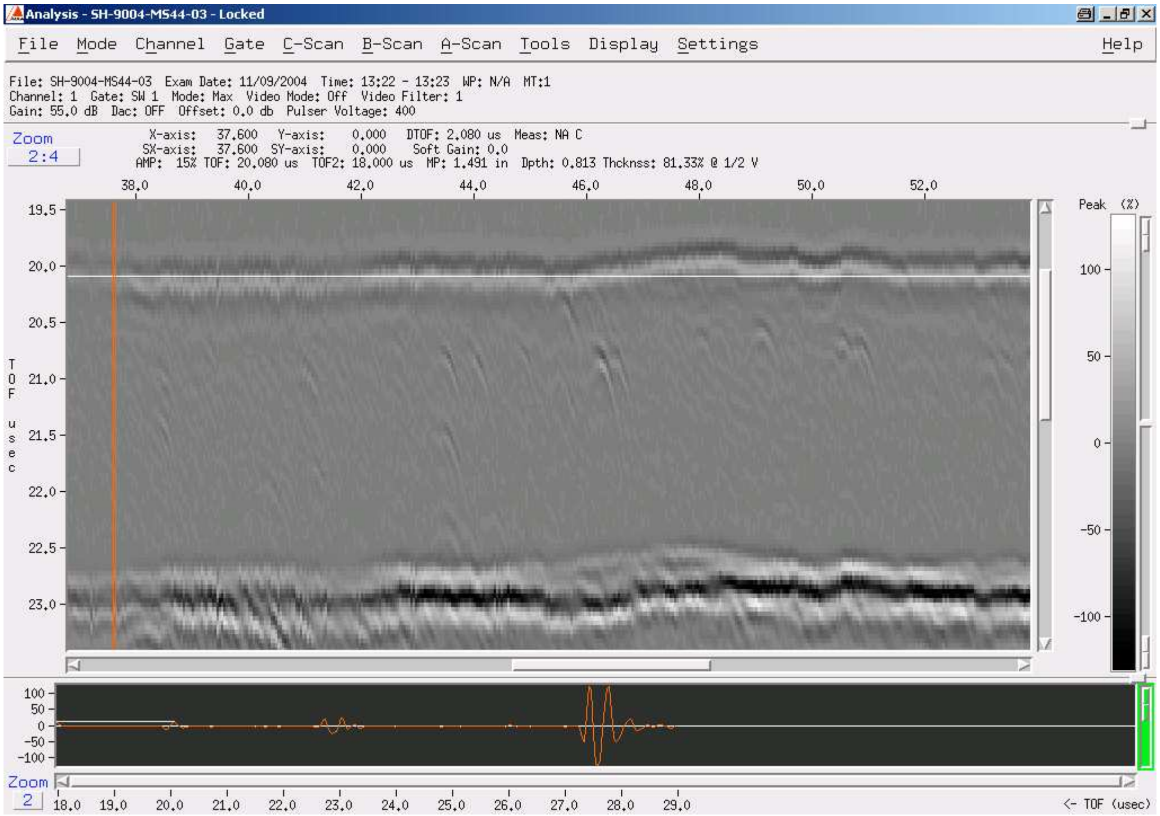


Image of Scattered Porosity – Low Amplitude, Very Small Pores

7 The results of the first phase

7.1 Comparison of RT and AUT detectability

In order to gain an understanding of the results reported by RT and AUT (TOFD) all the reports on the welds were reviewed for reported defects, both acceptable and repairable defects were considered. The comparison identifies the ability of the examination technique used to detect and report an identifiable defect – the probability of detection (POD). We have to remember both RT and AUT (TOFD) is a function of the equipment and the interpretation of the technician. The technician and the equipment form the detection system.

From literature the following statements and information on this question was gathered:
Dr. Bouma , *RTD (NL).* He has specialized in TOFD since 1993, and works with a team of 10 at RTD. He reported in 1993 that based on results from the Netherlands Welding Institute (NIL) study that TOFD showed 90% POD in contrast to pulse echo, which showed only 50%.

This is a statement relating TOFD as alternative to pulse echo.

Erhard A, and Ewert U. (The TOFD Method -Between Radiography and Ultrasonic in Weld Testing an article published in, DGZfP Jahrestagung, Celle, Mai 10-12, 1999) reported on a detail comparison of RT and UT taking wall thickness in consideration as well. This article specifies that RT or UT may be used for plate between 15 mm and 40-mm thickness. The probability of detection vs. flaw size is shown in the graph.

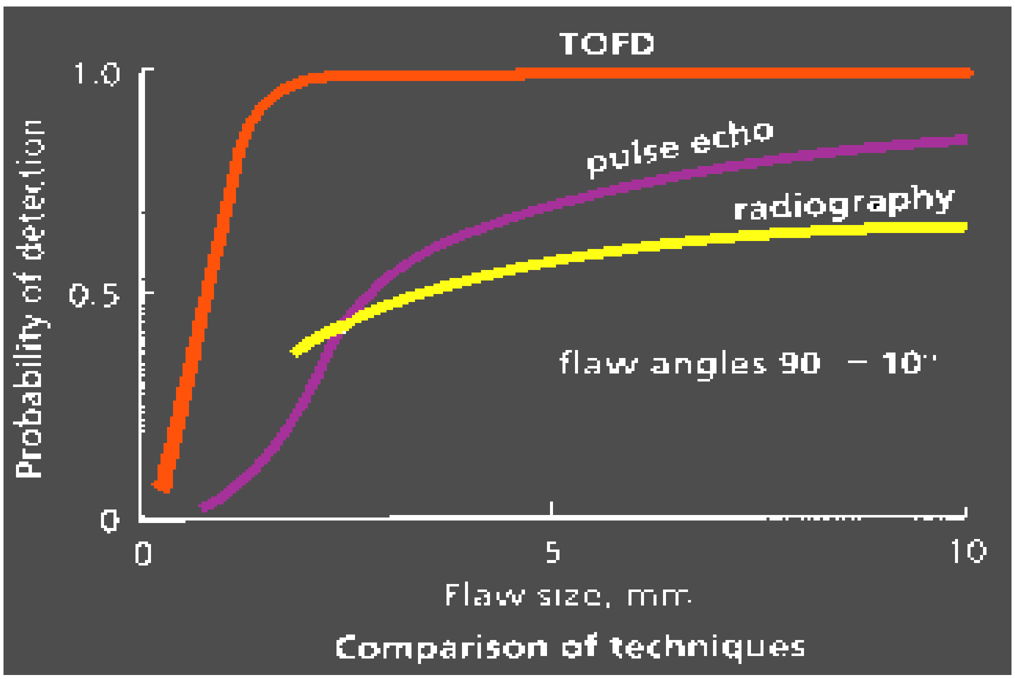


Figure: Probability of Detection for NDT Methods (by AEA QT News Article)

7.2 The steam pipeline - field welding

The pipeline set-up is shown in the following photographs.

A Field Weld

A Weld Repair

7.3 The results from RT and AUT (TOFD)

The following table is an extract from the database comparing the defects reported by RT and AUT on the circumference of each weld.

Table of defects (abstract) detected in welds by RT and AUT

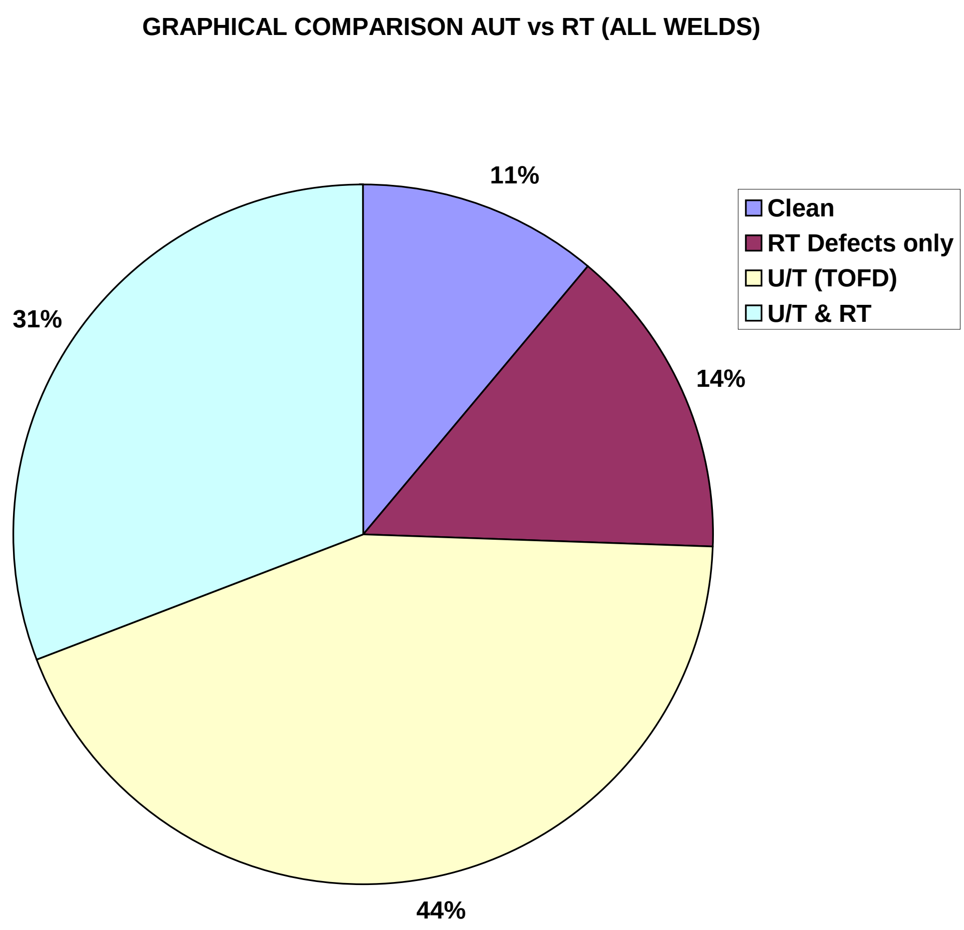
	Position of defect on circumference																							
Weld No.	**0-6**		**6-12**		**12-19**		**19-25**		**25-31**		**31-37**		**38-44**		**44-50**		**50-57**		**57-63**		**63-69**		**69-75**	
	RT	**UT**	**RT**	**UT**	**RT**	**UT**	**RT**	**UT**	**RT**	**UT**	**RT**	**UT**	**RT**	**UT**	**RT**	**UT**	**RT**	**UT**	**RT**	**UT**	**RT**	**UT**	**RT**	**UT**
LS40-1				X										X		X				X				X
LS40-2	X	X				X						X				X		X				X		
LS40-3						X																		
LS40-4		X				X		X										X						X
LS40-5		X								X				X				X						X
LS40-6													X					X				X		
LS40-7		X		X							X			X		X		X			X	X	X	X
LS40-8													X		X		X							
LS40-8WT														X				X						
LS40-9	X																							
LS40-9R																								
LS40-9RS	X	X		X				X						X				X				X		X
LS41-1				X						X		X			X									
LS41-2	X	X		X		X				X		X		X		X			X	X				X
LS-41-3								X																
LS41-4		X		X		X				X				X			X					X		X
LS41-5																					X		X	
LS41-5R				X																				X
LS41-6																								X
LS41-7				X						X				X				X				X		
LS41-8						X			X	X	X		X											
LS41-9		X		X						X		X		X										
LS42-1				X		X										X				X				

The number of welds reviewed during phase two were as follows:

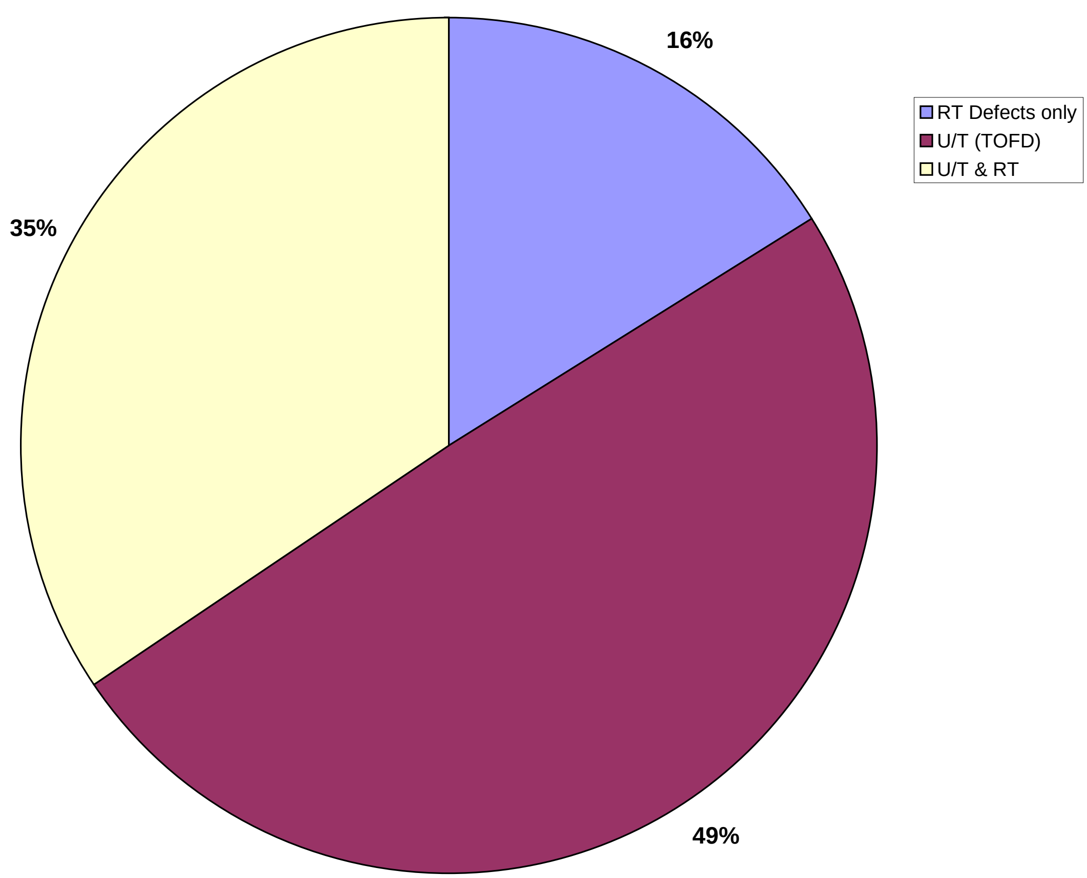
Total welds RT and AUT = 136 welds
Number of welds – no defects = 17 welds
(Confirmed by both RT and AUT)
Number of welds with defects identified by RT only = 22 welds

Number of welds with defects identified by AUT only = 67 welds
Number of welds with defects identified by RT & AUT = 47 welds

The first pie graph shows the distribution of defects detected by RT and AUT for all welds. The second pie graph show the detectability of RT vs. AUT if we assume all reportable defects were detected by the two methods:



AUT & RT COMPARISON CHART OF DEFECTS ONLY



Given the results shown we can deduct the following:

- For this application the radiography has a 51% probability of detecting a reportable defect.
- And using AUT (TOFD) we have an 84% probability of detecting a reportable defect.

The results reported for the steam pipeline correlate with the graph shown above for the POD of TOFD and RT as reported by AEA.

The aspects of **false calls** were addressed during construction but the data available did not allow for any conclusions to be made at this stage. However the influence of the technician in this aspect did play a role, for both RT and AUT (TOFD).

8 Conclusion

What did we learn out of this analysis?

What this study miss at this stage of the analysis is two things:

- Did both NDE techniques miss any defects? – We do not know and will only know if we have a failure of an undetected defect.
- The analysis does not yet compare the repairable defects. Did both techniques identify all the unacceptable defects? This will be the assumption for now.

The uncertainty or risk relating to the quality of the welds has been addressed successfully. We fully investigated the parameters related to measuring the quality of the weld as part of the risk mitigation during design and construction phases of the steam pipeline's life cycle.

The stress level of an as designed weld and the strength and toughness of a weld is known if the correct welding procedure is followed.

It was possible to monitor the quality of the welds successfully during construction. There is a high confidence level that critical defects have been identified and assessed. Either RT or AUT (TOFD) has reported those unacceptable defects to code and corrective action has been taken.

It was also found that sizing and definition of a defect's position was better done by pulse echo UT (hand scan).

The study is not yet complete from engineering point of view, some issues mentioned earlier needs further investigation. The detection of crack like defects that is planar was not yet analysed. However the experience on the steamline and previous work indicated (as expected) that AUT (TOFD) was more successful in detecting these defects. There was a concern for lack of sidewall fusion because of the weld design (double - V).

An issue for further investigation is close to surface defects (in the weld cap) and root defects. These two areas definitely need to be investigated and compared.

This investigation does not challenge the ASME Code Case 2235, "Use of Ultrasonic Examination in Lieu of Radiography." For heavy wall pressure vessels (> 40mm) it is expected that the results may be different.

As for the question: **Is it AUT or RT?** This question was asked so many times by inspectors, engineers and contractors.

The answer is a definite **YES you have to do AUT and RT** if you want to reduce the risk of missing possible unacceptable defects. The one technique is complimentary to the other.

9 Acknowledgements

I like to thank all those that participated and contributed to the success of the quality engineering effort of this project especially the welders, technicians and inspectors in the field for doing an excellent job.

Also special thanks for the information provide by Eric Sjerve, IRIS NDT.

Also to the engineers that started the risk reduction process and contributed their knowledge to the welding process design, Hennie Prinsloo, Jacek Mielzcarek, Derek Wilkenson and those that I never met.

Last but not the least the lab technologists for their help with testing especially Perry Richard who also helped with the data analysis.

10 References:

- CSA Oil and Gas Pipeline Systems code, Z662-03.
- J X Wong e M L Rauch – Risk Engineering and Management, Marcel Dekker, New York
- Dr J S Busby, Final Report on Credible Risk Assessment, Department of Mechanical Engineering, University of Bath, August 2003
- A study done by J B Wintle a.o. at TWI, in 2001
- **Dr. Bouma,** RTD (NL), 1993.
- Erhard A, and Ewert U. The TOFD Method -Between Radiography and Ultrasonic in Weld Testing an article published in, DGZfP Jahrestagung, Celle, Mai 10-12, 1999

Appendix A

Some background on TOFD

Remarks by Udo Schengermann of Krautkraemer at a meeting in Dortmund on 13 May, 1997:

Mr. Udo Schlengermann of Krautkraemer introduced the TOFD technique. He was one of the creators of the TOFD pre-standard 583 part 6 and was also involved in the development of the British Standard BS 7709 1993

Here is an outline of Mr. Schlengermann's remarks:

- Evaluation of diffracted signals was not invented by TOFD. It is possible to apply only one probe to measure crack depth by use of the diffracted signals at a crack tip. However that is very imprecise since velocity is unknown and the angle relates to the material. It is also possible to measure crack depth using of the corner effect together with the diffracted signal. That is not TOFD either.
- Diffracted waves have a different velocity than reflected longitudinal waves.
- The TOFD method only evaluates diffracted echoes which are 20dB smaller than the reflected echoes.
- The location of a flaw can be determined at the time of flight minimum, but that is more or less imprecise.
- Diffraction is stronger for longitudinal waves than for transversal waves.
- The standard is the use of longitudinal probes, 50° to 70°, small crystal, with widely spread sound beam to cover the whole defect.
- The two diffracted signals of the crack tip are generated with a 180° phase shift. The distance between the two signals on the time scale is nonlinear.
- TOFD always uses RF signals to display images, (minus = white, plus = black), although colors could be used.
- Images showing arcs which shapes can be used to illustrate the geometry of the flaw. Image post processing was applied to improve the image. It has always been assumed that images of defects can be better interpreted with TOFD than with A-scan images. However, this side-by-side-comparison disproves that.
- A disadvantage is that the gain must be very high, which produces a very high back wall echo and it is is not suitable for coarse grained materials.
- An image catalog has to be established. Example for a weld: Lack of root penetration, lack of side wall fusion, slag, porosity.
- The probe frequency should be 10 MHz or higher, frequencies under 5 MHz are not applicable.

- The Brit. Standard 7706 uses a calibration block with a V notch. The instrument gain is not defined. The EN pre-standard 586-6 uses side drilled holes with slits to the surface
- TOFD can perform more exact sizing than the reflection method.
- Crack edges must be sharp, and they aren't always!