Sensitivity Response of Total Focusing Method (TFM) for Weld Inspection versus Other Techniques

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CINDE
CANADIAN INSTITUTE FOR NON-DESTRUCTIVE EVALUATION

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Agenda

1. Introduction
2. Go Back to the Basics
3. Methodology
4. Results
5. Conclusion

Section 1 | Introduction

1. Introduction

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  NDT Specialist at NUCLEOM, QC

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1. Introduction

How TFM can be compared to PAUT, RT and even a destructive technique like metallography ?

How the CIVA simulations in TFM made by Ms Kombossé Sy in her doctoral thesis can be compared with real defects in a weld?

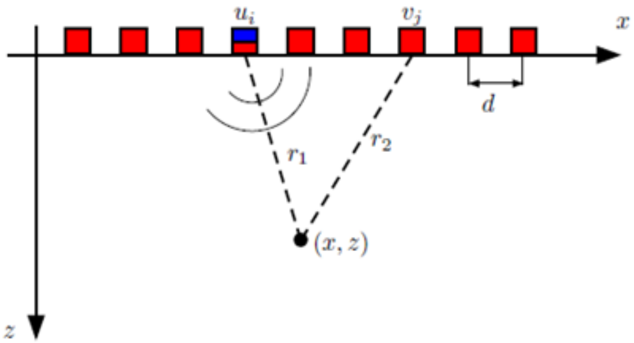
Is there a unique TFM propagation mode that can detect all real flaws in a weld ?

Section 2 | Go Back to The Basics

2.1 FMC/TFM DEFINITIONS

What Is Full Matrix Capture ?

- **Acquisition technique** where **every element** of a phased array transducer **is individually pulsed. Sound** is then **received on every element, including the transmitter**.

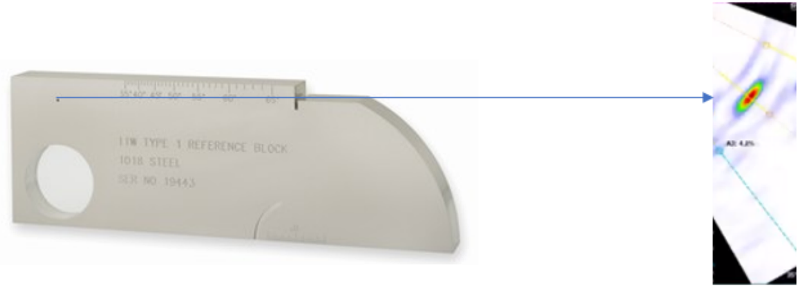


What is Total Focusing Method ?

- **Ultrasonic imaging technique** that occurs in the **post-acquisition** phase of an **FMC inspection**.

FMC Acquisition → Raw A-scan + algorithm → TFM image in a clear visual format

2.2 Amplitude for PAUT Technique



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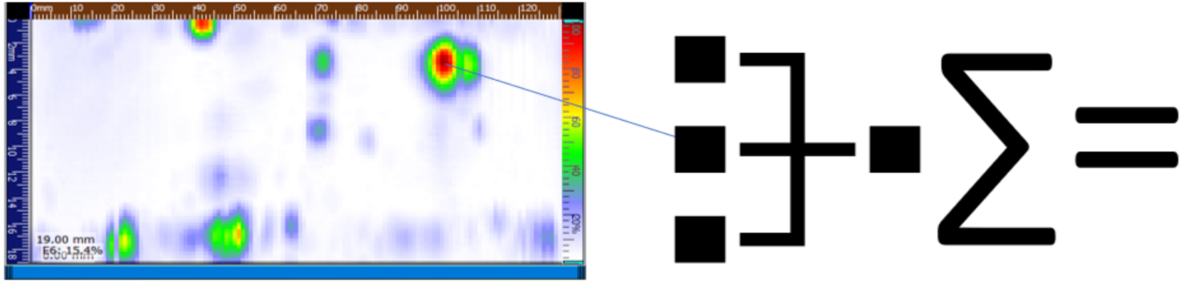
Physical Hole reference = Amplitude Reference for the whole scan

- In PAUT, the amplitude of a known reflector of a calibration block is compared to the amplitude of a discontinuity.
    - Amount of energy returned by a reflector to the transducer is compared to the reference level.

2.3 Amplitude for TFM Technique



Highest reconstruct amplitude response of the acquisition = Amplitude Reference for the whole scan

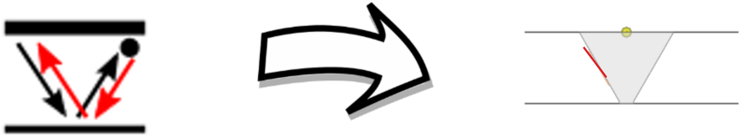
- For the Sonatest solution, each pixel is associated with an amplitude value that varies between 0% and 100%.
    - A pixel with a value of 100% has the biggest amplitude among the other pixel **for a given area.**
    - FMC/TFM is not standardised yet.

2.3 AMPLITUDE FOR TFM TECHNIQUE

Mode TT

Mode TTT

Mode TT-TT



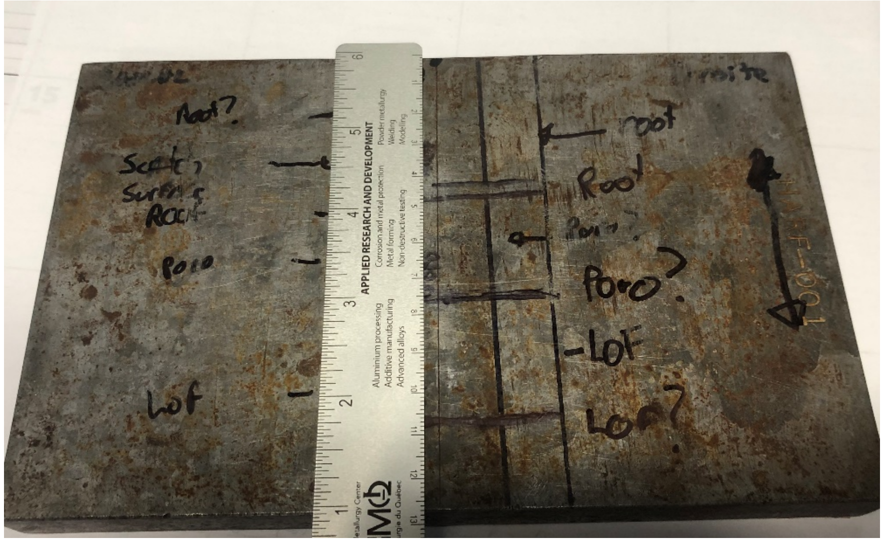
- Specific propagation modes are suitable depending on the flaw orientation.

In TFM, a default will have a high amplitude when the propagation mode is optimal for it.

Section 3 | Methodology

3. METHODOLOGY

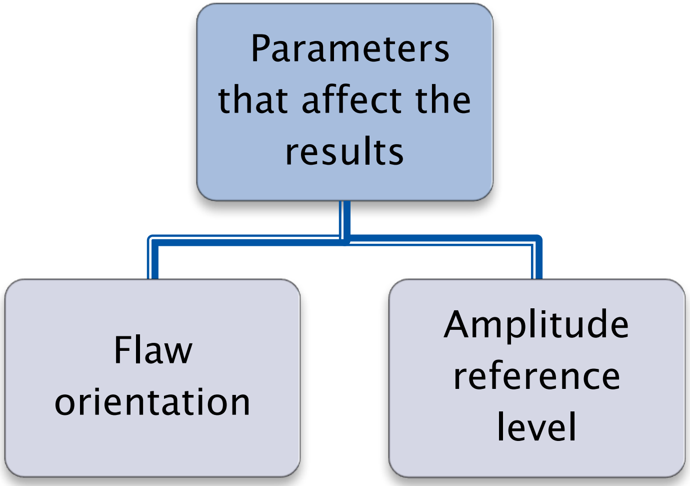
- Specimen: Carbon steel plate
- Thickness: 19 mm
- Weld type: Unknown
- Flaw location: Unknown



3.1 ULTRASONIC METHODOLOGY

- Apparatus: Phased-array equipment (32:128PR)
- Probe frequency: 5 MHz
- Calibration done: velocity, wedge delay, sensitivity and TCG

MULTISCAN : PAUT and FMC acquisitions were performed at the same time, with the same probe on the same device.



3.2 Radiography Methodology

- The initial exposures were carried out with analogue film and then adapted to other techniques.
- 3 exposures (0°,+45°,-45°) were performed for each technique

Table 1 - Analogue film parameters

Distance between the source of the film	914 mm
Energy	200 kV
Exposure	2700 mA•sec.
Film brand	Carestream Industrex MX125
Pb intensity screen	0.127 mm front and 0.254 mm back
Filtration added to the X-ray tube	None
Optical density	2.5

3.2 Radiography Methodology

Computed Radiography Technique

- Exposure + Energy level = Same
- Laser power + photomultiplier (PMT) were adjusted
- Copper screen was used between the back of the imaging plate and the intensifying screen to prevent any lead fluorescence.
  - That could degrade the signal-to-noise ratio (SNR) of the image

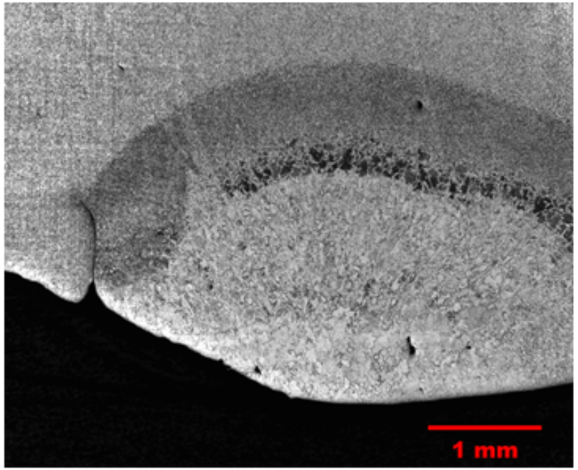
Digital Radiography Technique

- Main objective: Achieve similar SNR and contrast-to-noise ratio (CNR)
  - Energy rise to 240 kV + additional filtration +digital detector array (DDA) was put farther from the floor = reduce the scattered radiation and the noise

3.3 Metallography Methodology

Metallography consists to study metal structure with the help of a microscope.

Metallography's were made vis-a-vis certain defects found with PAUT and TFM techniques.



1. Grinded phase
   - Silicon carbine paper from 180 to 1200 grits
2. Finishing polishing
   - Polycrystalline diamond solutions
3. Etching
   - Nital etch 2% during approximately 15 seconds

Section 4 | Results

4.1 METALLOGRAPHY

Lack of fusion and porosity

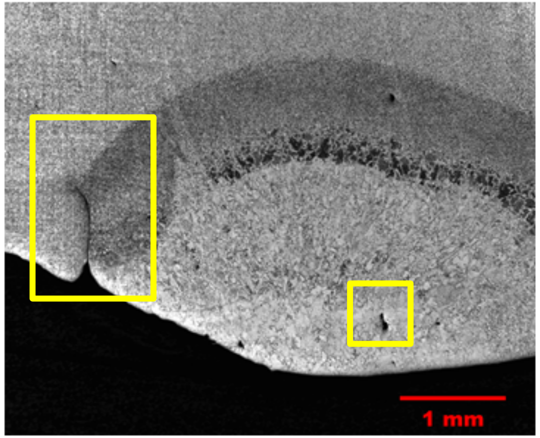


Figure 6 – Metallography of the flaw A

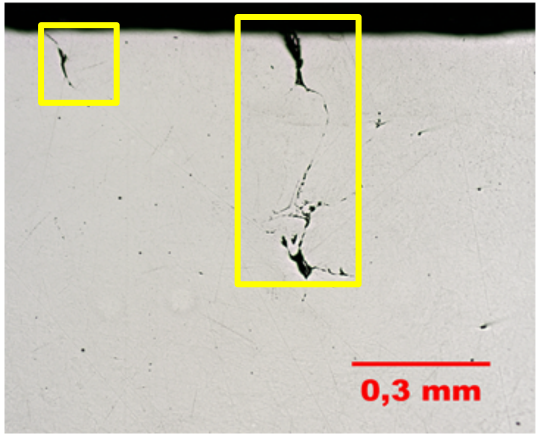


Figure 7 – Metallography of the flaw B

Cracks landing to the surface

Porosity

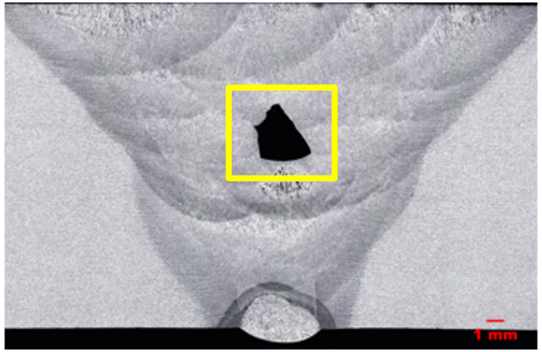


Figure 8 – Metallography of the flaw D

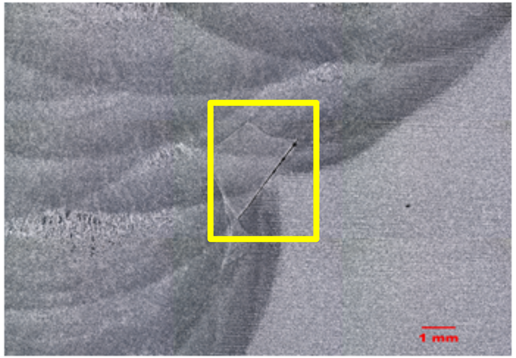
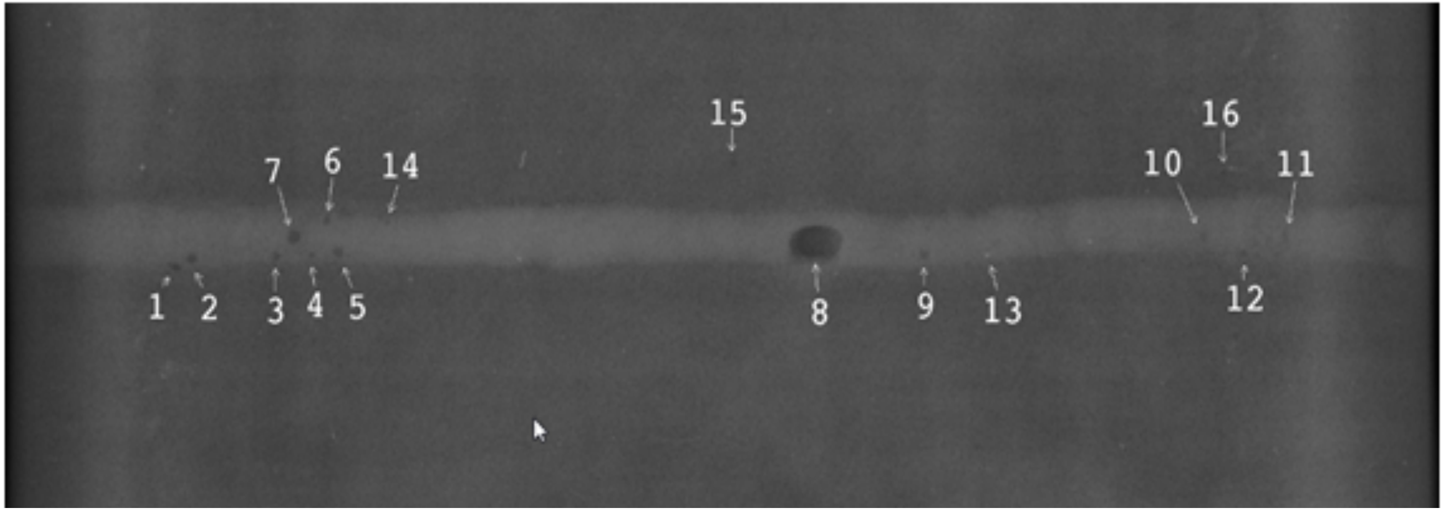


Figure 9 – Metallography of the flaw E

Lack of fusion

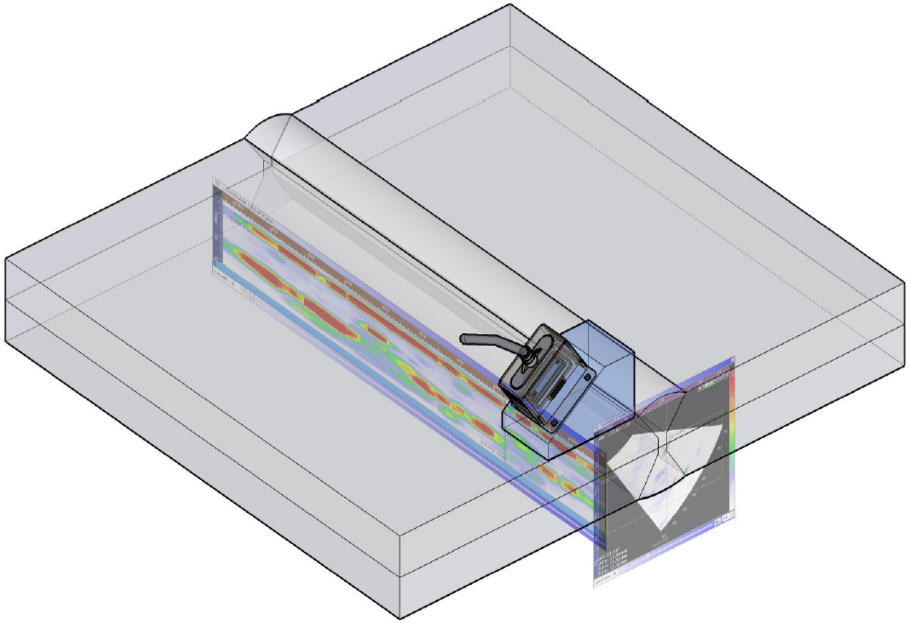
Computed radiography where the root of the weld is visible.



- The numbers refer to porosities, except #13.
- #13 is an inclusion

4.3 PAUT AND TFM

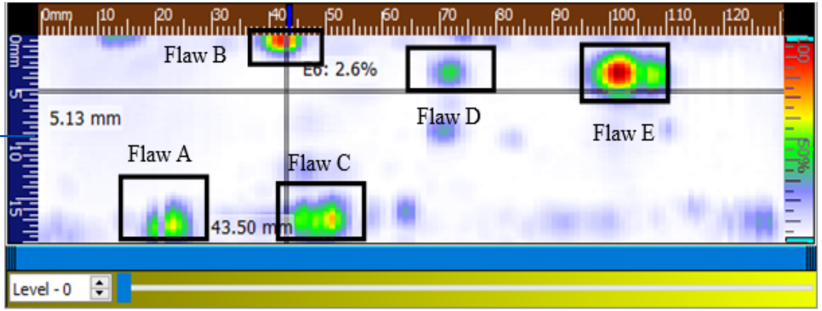
The PAUT End view is a projection side which helps the user have a global view of the inspection.

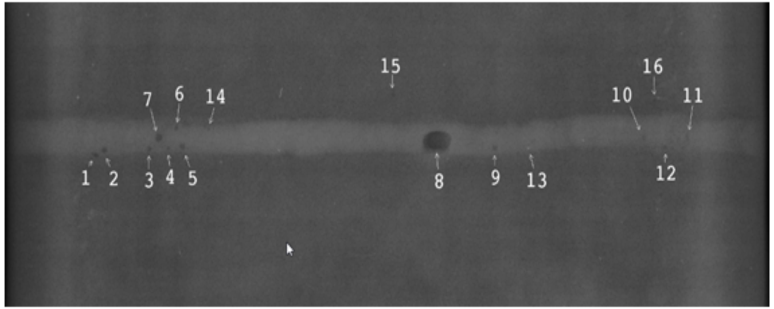


MULTISCAN : PAUT + FMC acquisitions at the same time.

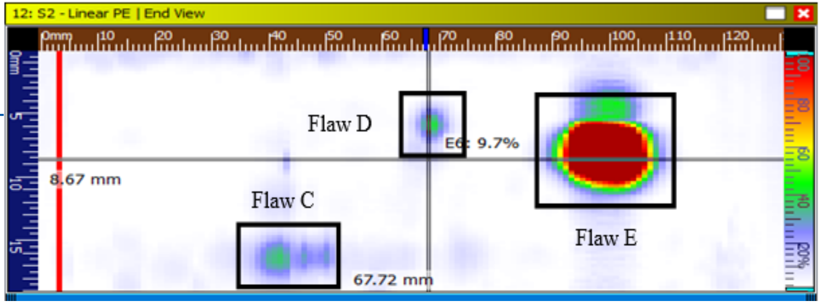
4.1 RT AND PAUT

End view of the left side of the weld





End view of the right side of the weld

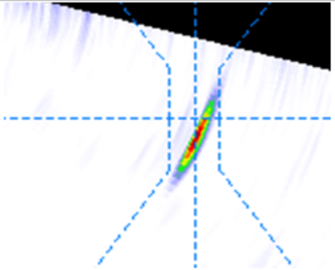
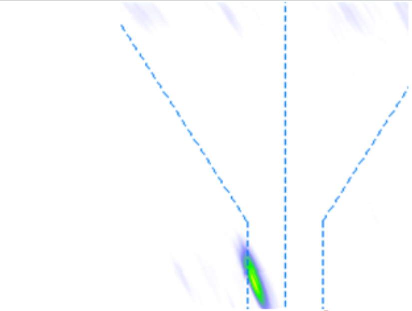
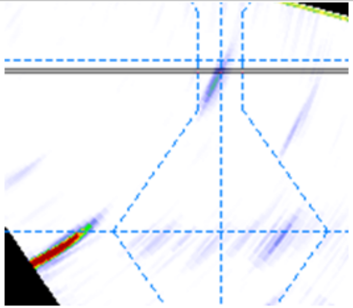
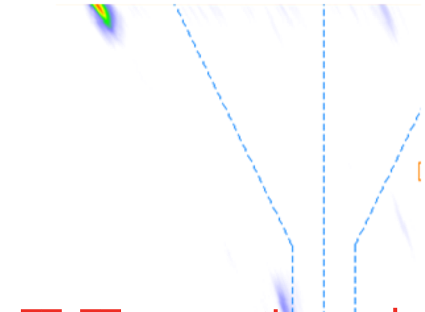


It is important to scan from both side

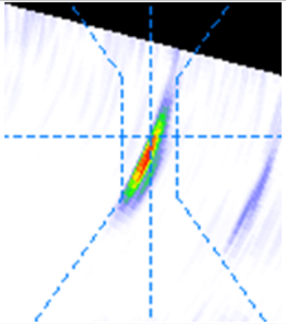
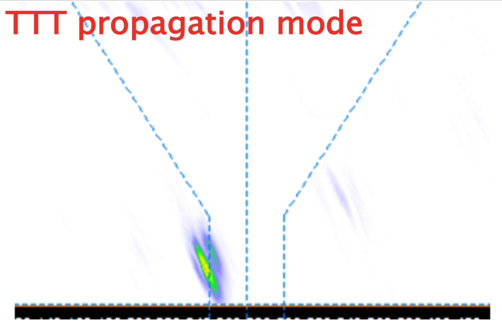
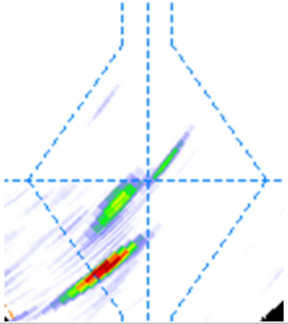
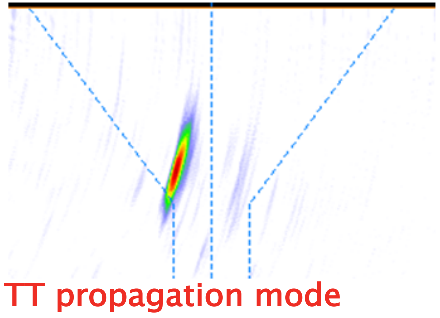
Observations

- **RT is more sensitive with volumetric flaws,** such as porosity and inclusion. On the other hand, **PAUT is more sensitive for planar discontinuities**, such as crack and lack of fusion.
- All discontinuities visible with PAUT are also visible with TFM.
- The **major advantages of the TFM** is having **very high-resolution images** and the **acoustic energy is virtually focused** everywhere inside the weld volume.
  - The excellent resolution and image clarity is directly related to the choice of the propagation mode.

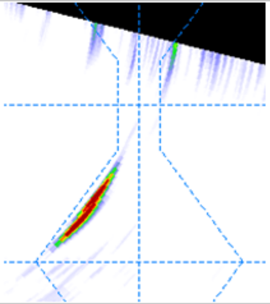
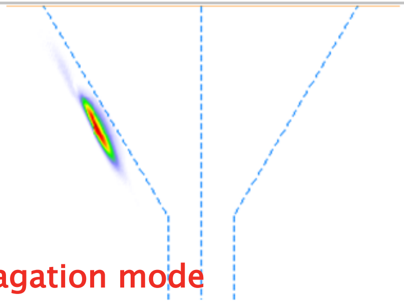
4.1 Overview of the Results

Flaw A		**Flaw B**	
PAUT	TFM	PAUT	TFM
	 TT propagation mode		 TT-TT propagation mode
Type of defect: Lack of fusion		Type of defect: Crack	
Location: 20 mm based on the scan axis		Location: 42 mm based on the scan axis	
Acoustic information: Strong amplitude response at the bevel or at the root		Acoustic information: Planar defect with distinguished amplitude response	
Is it detectable with: ☐ RT ☒ Metallography (see Figure 6)		Is it detectable with: ☐ RT ☒ Metallography (see Figure 7)	

4.1 Overview of the Results

Flaw C		Flaw D	
PAUT	TFM	PAUT	TFM
			
Type of defect: Porosity		Type of defect: Porosity	
Location: 50 mm based on the scan axis		Location: 70 mm based on the scan axis	
Acoustic information: Echo cluster in the weld volume		Acoustic information: Echo cluster in the weld volume	
Is it detectable with: ☐RT ☒Metallography		Is it detectable with: ☒RT (see Figure 5, #8 of the radiography film) ☒Metallography (see Figure 8)	

4.1 Overview of the Results

Flaw E	
PAUT	TFM
	 TT-TT propagation mode

Type of defect: Lack of fusion
Location: 100 mm based on the scan axis
Acoustic information: Strong amplitude response at the bevel or at the root
Is it detectable with: ☐ RT ☒ Metallography (see Figure 9)

4.2 Amplitude Consistency toward Flaw Orientation

- The green boxes highlight the maximum amplitude for a given mode.

Mode	Acquisition of the left side of the weld									
	Flaw A Lack of fusion		Flaw B Crack		Flaw C Porosities		Flaw D Porosities		Flaw E Lack of fusion	
	Amplitude (%)	dB diff.	Amplitude (%)	dB diff.	Amplitude (%)	dB diff.	Amplitude (%)	dB diff.	Amplitude (%)	dB diff.
PAUT	100,8	-6,0	177,8	-1,0	102,0	-5,8	112,0	-5,0	200,0	0,0
TT	100,0	0,0	47,0	-6,6	80,6	-1,9	84,9	-1,4	67,4	-3,4
TTT	100,0	0,0	10,0	-20,0	85,7	-1,3	21,5	-13,4	27,4	-11,2
TT-TT	60,4	-4,4	84,9	-1,4	68,1	-3,3	39,7	-8,0	100,0	0,0

- No unique TFM propagation mode can detect all the defects.
- TT, TTT and TT-TT modes are quite good for the lack of fusion.
- In TTT, the crack with an amplitude of 10% and with 20 dB difference is considered undetected.
- The porosities are better detectable with TT mode.

4.2 Amplitude Consistency toward Flaw Orientation

- The green boxes highlight the maximum amplitude for a given mode.

Mode	Acquisition of the right side of the weld									
	Flaw A Lack of fusion		Flaw B Crack		Flaw C Porosities		Flaw D Porosities		Flaw E Lack of fusion	
	Amplitude (%)	dB diff.	Amplitude (%)	dB diff.	Amplitude (%)	dB diff.	Amplitude (%)	dB diff.	Amplitude (%)	dB diff
PAUT	---	---	---	---	97.1	-4.4	83.3	-5.8	161.9	0.0
TT	---	---	---	---	34.1	-9.3	100.0	0,0	76.4	-2.3
TTT	---	---	---	---	45.1	-6.9	31.7	-10.0	100.0	0.0
TT-TT	---	---	---	---	9.1	-20.8	9.9	-20.1	100.0	0.0

- **No unique TFM propagation mode can detect all the defects.**
- Lack of fusion has a strong amplitude with TT-TT propagation mode.
- The porosities are much better detected with TT mode
  - This could be explained by a smaller sound path compared to TT-TT mode.

4.2 Amplitude Consistency toward Flaw Orientation

Mode	Mean dB deviation
PA	-4.78
TT	-4.58
TTT	-9.96
TT-TT	-12.37

- **PAUT technique is less sensitive to defect orientations** compared to individual propagation modes.
- **In TFM, such variations** usually occurs when the **propagation mode and the flaw orientation are not compatible with each other.**
- This table highlights the unlikeliness of qualifying a weld qualification sample based on ASME section V, article IV, Mandatory Appendix IX

Section 5 | Conclusion

How the CIVA simulations in TFM made by Ms Kombossé Sy in her doctoral thesis can be compared with real defects in a weld?

- By **using the simulation results in an experimental setup, based on a real FMC acquisition** testing a physical weld sample.

- PAUT and TFM comparisons support that **efficient resolution is achieved better utilising the TFM approach with the appropriate propagation mode.**

Is there a unique TFM propagation mode that can detect all real flaws in a weld ?

- It is doubtful that a single propagation mode could validate the integrity of a weld qualification sample.
- Utilising all three TFM propagation modes (TT, TTT and TT-TT) improve the resolution and the sizing capabilities and minimising the risk of negligent due to defect orientations.