Ultrasonic Inspection of Bolts, Pins and Shafts

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Topics:

- Job Assessment
- Equipment Selection
- Calibration
- Scanning
- Evaluation
- Recording & Reporting

Job Assessment

- Why is it being inspected?
- What is the expected mode of failure?
- Do you have a reliable drawing?
- Do you know the history of the component?
- Can you get access to both ends?
- What secondary NDT methods are available?
- Do you need a specific procedure for this component?

Equipment Selection

UT Set

- Range
- Signal to Noise Ratio
- PRF
  - Cause of many false calls
- Image Capture Capabilities
- Advanced Systems – PA/ShaftTest

Probe Selection

- Frequency selection secondary to Near Zone length
- Beam profile – Beam Spread and Near Zone

			Beam Diameter @ (mm)		
Frequency	Diameter	NZ	250	500	2000
5	12	30	22	43	174
5	24	122	11	22	87
2	12	12	54	109	435
2	24	49	27	54	217

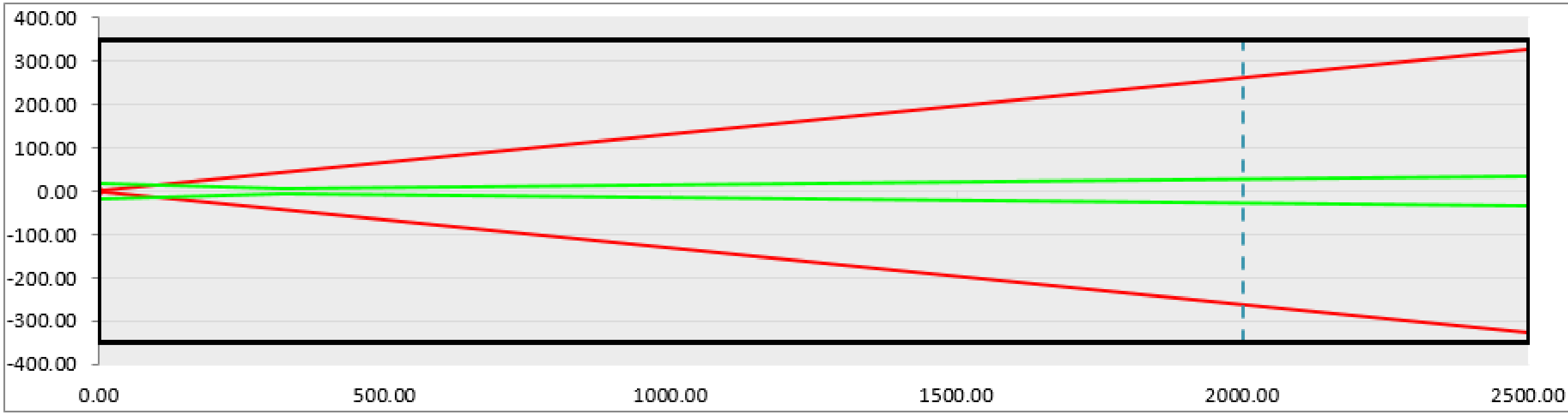
- Resolution – Pulse Length
  - Short Pulse = Improved Resolution
    - Essential for resolving cracking out of lubrication lines etc.
    - Pulse length < ½ line diameter recommended
  - Long Pulse Increased Penetration
    - Not commonly required due to nature of forgings

Probe Selection
Beam Profile – Beam Spread and Near Zone

Probe 1					
Frequency (MHz)	Diameter (mm)	Velocity (km/s)	NZ (mm)	Beam Dia @ FD (mm)	Beam Dia @ Depth x (mm)
2	10	5.9	8.5	2.2	521.6

Position
x
2000.0

Probe 2					
Frequency (MHz)	Diameter (mm)	Velocity (km/s)	NZ (mm)	Dia @ FD (mm)	Beam Dia @ Depth x (mm)
5	39	5.9	322.2	8.6	53.5



	Area	BW Compared to 6mm FBH @ Pos X	
	Area (mm^2)	Area Ratio	Approx dB
Probe 1	213675.5	7556.2	78
Probe 2	2247.7	79	38
Difference	95.0625	95.1	40

Created by Paul Grosser

Length	**2500**
Diameter	**700**

Calibration & Sensitivity

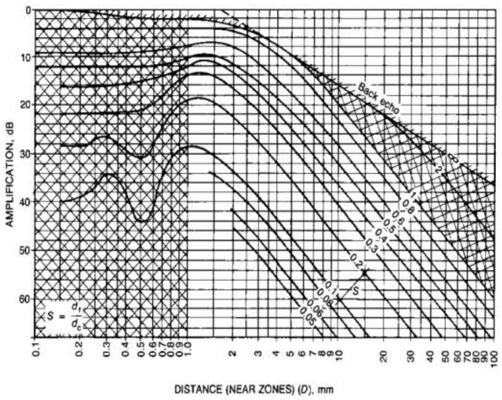
- Follow your procedure

- Back Wall Echo
  - BWE most common
  - Takes into account specific attenuation of the component
  - Beware that the BWE is actually the BWE and not a complete fracture
    - e.g. broken bolt under the head, testing from thread end

- Flat Bottom Holes
  - Use care if nominating equivalent FBH sizes
  - Zero degree and FBH’s, tends to undersize real flaws, whilst in linear sensitivity range

- Reference Samples
  - Great if you have access to them

- Sensitivity
  - Discontinuity specific
  - Based on expected
    - Orientation
    - Size
    - Location
    - Minimum Critical Discontinuity Size
    - Frequency of Inspection



Scanning

- Follow your procedure

- Access
  - Both ends if possible

- Initial Overall Scan
  - Do a low gain base line scan
  - Where testing multiple items, compare attenuation, it may indicate an issue

- Multiple Probes
  - Consider the near zone lengths
  - Different probes may be required for different zones of the component

Evaluation

- Loss of Expected Response
- Comparison
- Mode Conversions
- Side Wall Phase Change Destructive Interference
- Interference Fits

Evaluation

- **Loss of Expected Response**
  - Change in temper due to bearing failure etc
  - Obliquely aligned discontinuities
  - Issue with heat treatment

Evaluation

- **Loss of Expected Response**

Evaluation

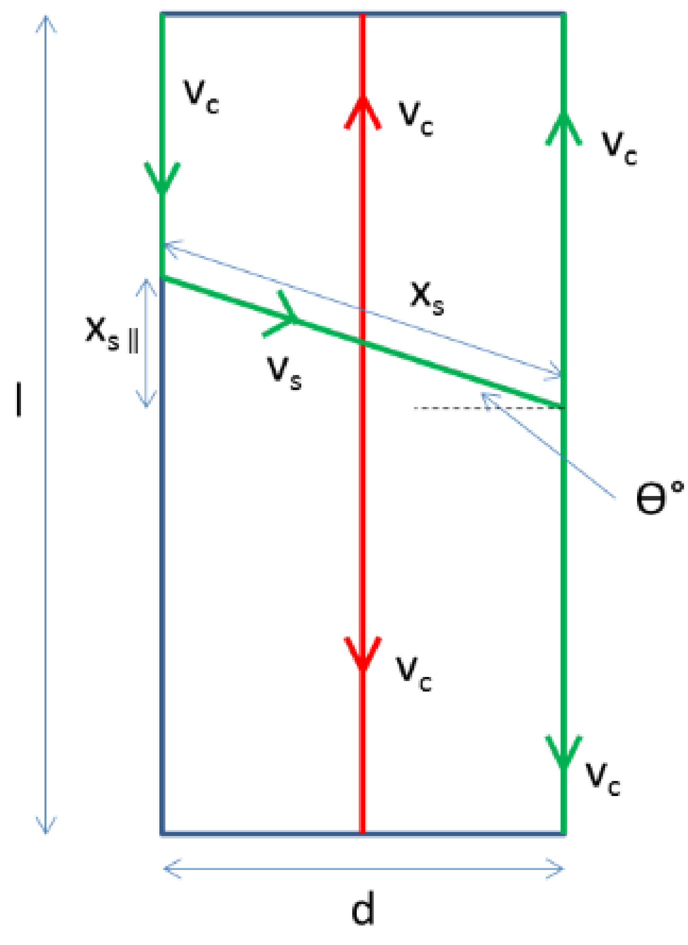
- **Comparison**
  - Wherever possible compare
    - Attenuation
    - Length
    - Unexplained Echo's

Evaluation

- **Mode Conversion (Transverse Wave Split-Off)**
  - Compression waves striking the boundary of the component at will mode convert into reflected shear
  - A range of shear wave angles are generated, however those generated near an incident angle of 90º result in the most obvious response
  - 90º incident results approximately 33° shear wave generated
  - The effect happens numerous times throughout the component

Evaluation

- **Mode Conversion (Transverse Wave Split-Off)**



Evaluation

- **Mode Conversion (Transverse Wave Split-Off)**

1. Time for compression wave to travel down and up:

$$t_c = \frac{2l}{v_c}$$

2. Time for compression wave with n shear reflections to travel down and up:

$$t_s = \frac{2l - nx_s}{v_c} + \frac{nx_s}{v_s}$$

$$t_s = \frac{2l - nd\tan\theta}{v_c} + \frac{nd}{v_s\cos\theta}$$

3. Time difference between compression wave and compression wave with n shear reflections to travel down and up:

$$\Delta t = t_s - t_c = \left(\frac{2l - nd\tan\theta}{v_c} + \frac{nd}{v_s\cos\theta}\right) - \frac{2l}{v_c}$$

$$\Delta t = nd\left(\frac{1}{v_s\cos\theta} - \frac{\tan\theta}{v_c}\right)$$

4. Conversion of time difference to depth distance difference for velocity (v_c)

$$\Delta x = \frac{v_c\Delta t}{2}$$

$$\Delta x = \frac{nd}{2}\left(\frac{v_c}{v_s\cos\theta} - \tan\theta\right)$$

5. Substituting Snell's Law

$$\sin\theta = \frac{v_s}{v_c}$$

$$\theta = \sin^{-1}\left(\frac{v_s}{v_c}\right)$$

$$\Delta x = \frac{nd}{2}\left(\frac{v_c}{v_s\cos\left(\sin^{-1}\left(\frac{v_s}{v_c}\right)\right)} - \tan\left(\sin^{-1}\left(\frac{v_s}{v_c}\right)\right)\right)$$

Evaluation

- **Mode Conversion (Transverse Wave Split-Off)**

6. Since $\cos\left(\sin^{-1}(x)\right) = \sqrt{1-x^2}$ and $\tan\left(\sin^{-1}(x)\right) = \dfrac{x}{\sqrt{1-x^2}}$ where $x = \dfrac{v_s}{v_c}$

$$\Delta x = \frac{nd}{2}\left(\frac{v_c}{v_s\sqrt{1-\left(\frac{v_s}{v_c}\right)^2}} - \frac{v_s}{v_c\sqrt{1-\left(\frac{v_s}{v_c}\right)^2}}\right)$$

$$\Delta x = \frac{nd}{2}\left(\frac{v_c^2 - v_s^2}{v_s v_c\sqrt{1-\left(\frac{v_s}{v_c}\right)^2}}\right)$$

$$\Delta x = \frac{nd}{2}\left(\frac{\left(v_c^2 - v_s^2\right)\sqrt{1-\left(\frac{v_s}{v_c}\right)^2}}{v_s v_c\left(1-\left(\frac{v_s}{v_c}\right)^2\right)}\right)$$

$$\Delta x = \frac{nd}{2}\left(\frac{\left(v_c^2 - v_s^2\right)\sqrt{1-\left(\frac{v_s}{v_c}\right)^2}}{v_s v_c - \frac{v_s^3}{v_c}}\right)$$

$$\Delta x = \frac{nd}{2}\left(\frac{\left(v_c^2 - v_s^2\right)\sqrt{1-\left(\frac{v_s}{v_c}\right)^2}}{\left(v_c^2 - v_s^2\right)\left(\frac{v_s}{v_c}\right)}\right)$$

Evaluation

- **Mode Conversion (Transverse Wave Split-Off)**

General formula for depth difference ratio with n shear reflections:

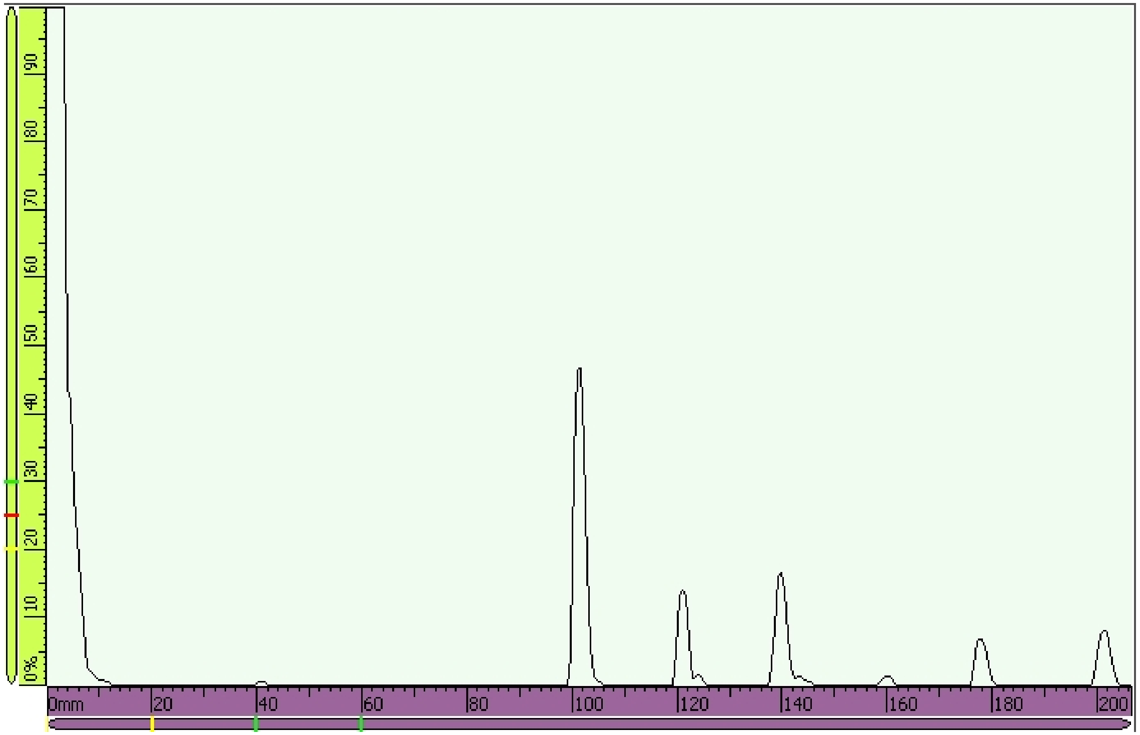
$$\Delta x = \frac{nd}{2}\left(\frac{v_c}{v_s}\sqrt{1-\left(\frac{v_s}{v_c}\right)^2}\right)$$, where n=1,2,3,....

For v_c **= 5920 m/s** and v_s **= 3220 m/s**

n reflections	Depth ratio
1	0.771d
2	1.543d
3	2.314d
4	3.086d

Evaluation

- **Mode Conversion (Transverse Wave Split-Off)**

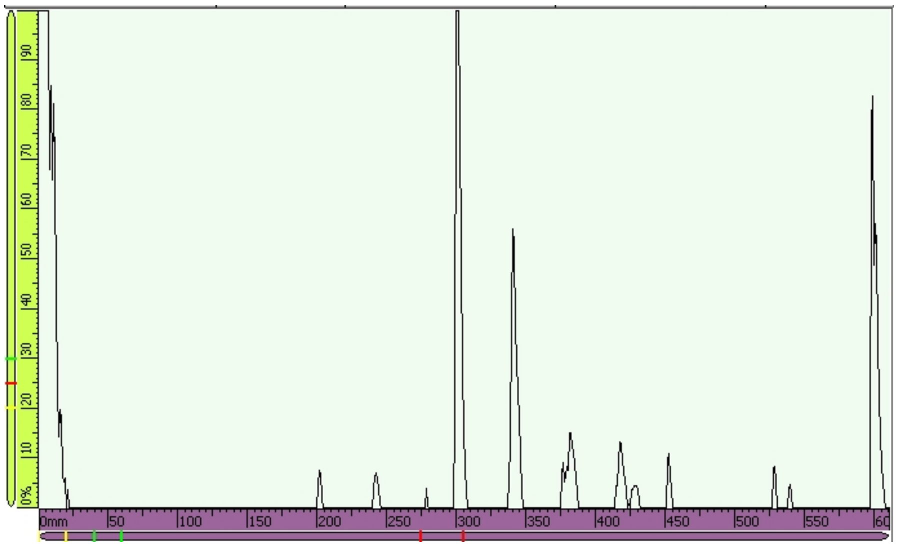


V1 Block Example

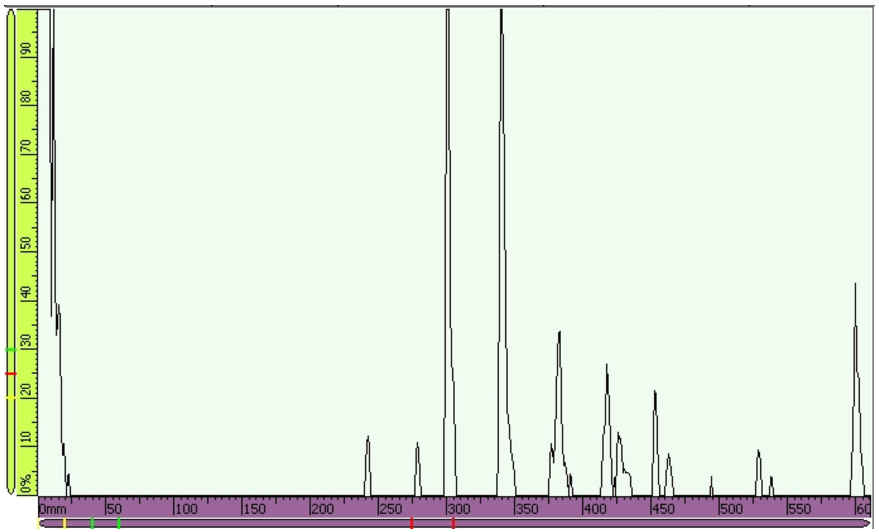
25 mm x 0.77 = 19.25 mm

Evaluation

- **Mode Conversion (Transverse Wave Split-Off)**



A



B

50 mm Diameter Pin

A: Crack at 200 mm with probe directly above crack
B: 1st Mode conversion from opposite side of pin, note increased amplitude

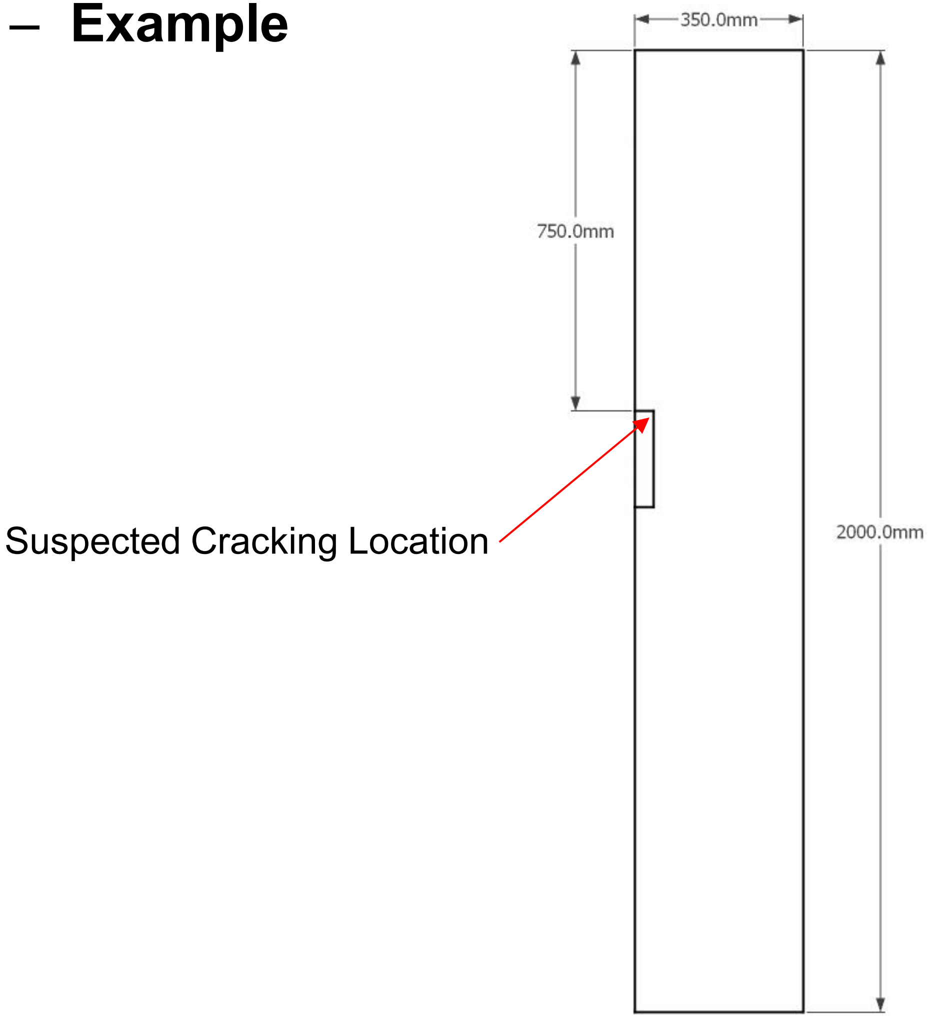
200 + (50 x 0.77) = 200 + 38.5 = 238.5

Evaluation

- **Mode Conversion (Transverse Wave Split-Off)**
  - 2nd Split result often the strongest
  - Signal for discontinuity often strongest from opposite side of part
  - Can occur after the BWE
  - Useful for detection of longitudinal cracks, as they mask (shadow) the mode converted signal
  - Tips
    - Calculate the split-off distances for known areas of concern
    - Whenever possible confirm from both ends
    - Monitor for additional signals after the back wall
    - Where possible use a low angle (e.g. 38° Shear Wave) for surface breaking transverse cracks. (Rail Industry has been doing this for a very long time with axles).

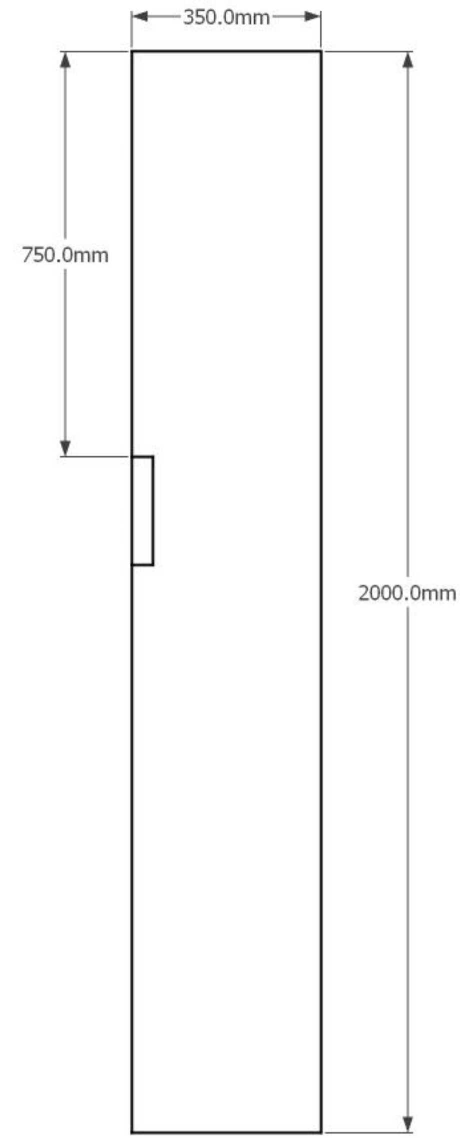
Evaluation

- **Mode Conversion (Transverse Wave Split-Off)**
  - **Example**



Evaluation

- **Mode Conversion (Transverse Wave Split-Off)**
  - Example
    - Split-off N^1 = 0.77 x 350 = 269 mm
    - Split-off N^2 = 1.54 x 350 = 539 mm
    - Direct Crack Screen Location = 750 mm
    - N^1 Screen Location = 1019 mm
    - N^2 Screen Location = 1289 mm

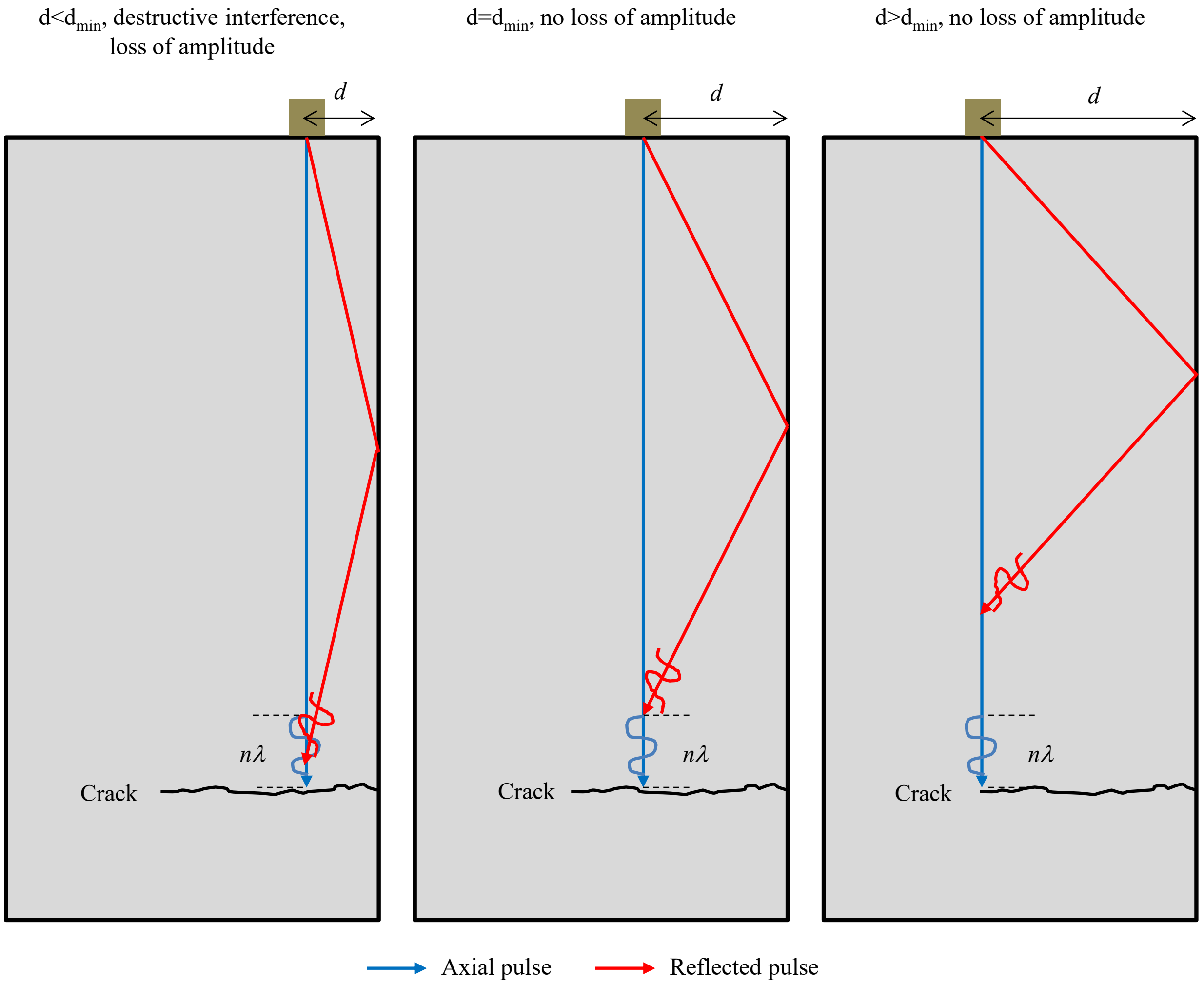


Evaluation

- Side Wall Phase Change Destructive Interference
  - Reflected compression waves undergo a $\lambda/2$ phase change
  - This results is destructive interference between the reflected wave and the direct wave
  - The closer the incident angle to 90° the greater the interference and cancelation between the reflected wave and direct wave. (ie: the closer the probe to the side wall, the greater the signal loss)

Evaluation

- **Side Wall Phase Change Destructive Interference**



Evaluation

- **Side Wall Phase Change Destructive Interference**
  - Typically, effects are minimised when the reflected beam lags the direct beam by the pulse duration

$$d = \sqrt{\frac{2sn\lambda - n^2\lambda^2}{4}}$$

Where:

d	= offset of probe from edge (mm)
λ	= wavelength (mm)
s	= depth of crack (mm)
n	= pulse duration in number of cycles

Evaluation

- **Side Wall Phase Change Destructive Interference**

Assuming a pulse duration of 4λ

Example: The approximate distance to avoid phase interference for a 200 mm deep, small surface breaking transverse crack with a 5 MHz probe would be:

$d > 21.6$ mm

Example: The approximate distance to avoid phase interference for a 200 mm deep, small surface breaking transverse crack with a 2 MHz probe would be:

$d > 33.8$ mm

Evaluation

- **Side Wall Phase Change Destructive Interference**
  - Hollow shafts exhibit major losses of energy due to phase change interference.
  - In some cases low angle shear wave inspections are more suitable than compression wave zero degree inspections.

Evaluation

- **Bearing Journals and Interference Fittings**
  - The presence of bearings and interference fittings can have a significant impact the distribution of sound in the part under test.
  - Can result in lost or transferred signals, mode conversions and spurious echo’s.
  - For critical in-situ inspections, the reference piece should where possible retain any journals or bearings.

Recording & Reporting

- Is there a previous report?
- What does the client really want to know?
- Are results reproducible based on your supplied information?
- Record 1st BWE to 80% SH as a comparison
- Record probe position
  - Maximum sensitivity for surface breaking transverse cracks may be away from the edge
- Wording?
  - Can you really say “No Cracking”?
  - Define your expected minimum detectable discontinuity type and size
    - ISO 17025 / NATA requirement for in-service inspection validations
  - This will be specified in your procedure
- Are results reproducible based on your supplied information?
  - I know its repeated but its vital for future monitoring…..

Examples:
Final Drive Shafts

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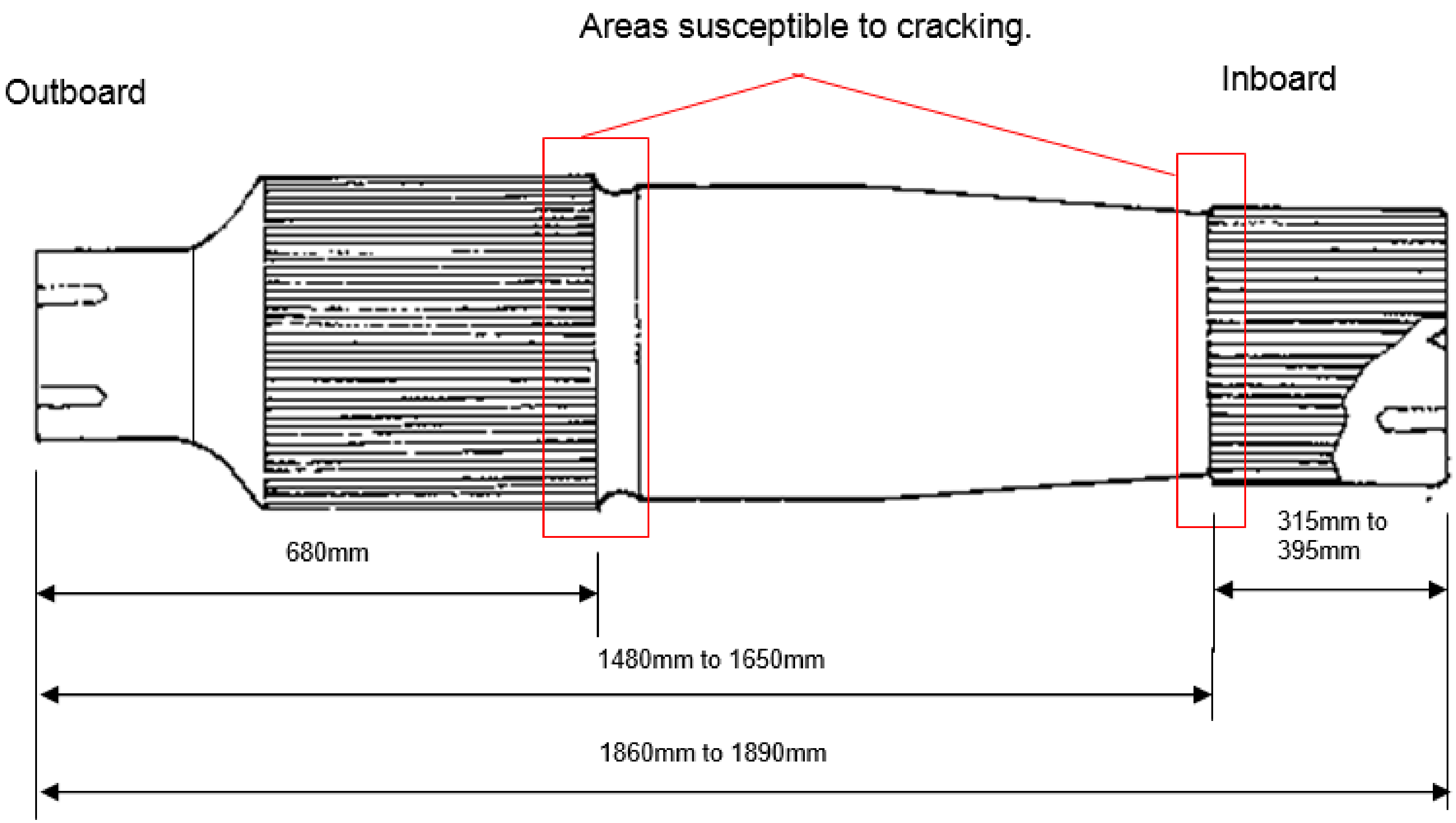
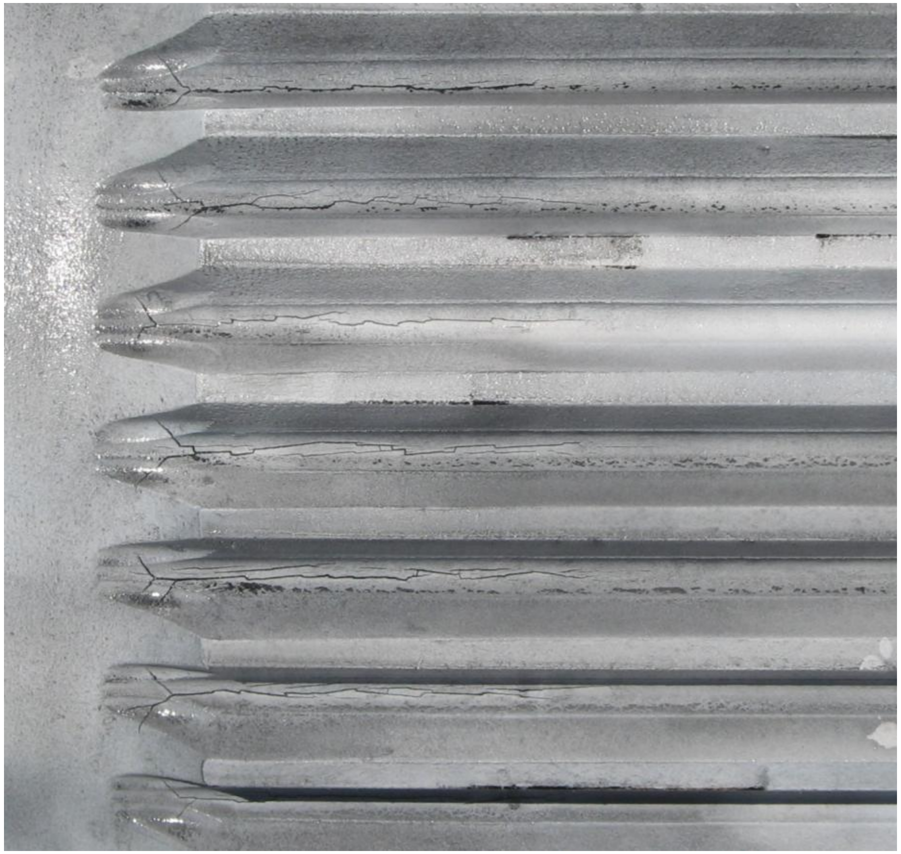


Examples:
Final Drive Shafts



- Know the mode of failure
- Not all in-service cracks will be transverse

Examples:
Final Drive Shafts

Examples:
BE1370 Propel Cam Shaft

Known for multiple mode conversions due to changes in section. Mode converted signals can align with position of likely cracking.

- Drawing essential
- Calculate signals from known mode conversion locations
- Test from both ends (not always possible in-situ)
- Work to specific cam shaft procedure

Examples:
Ball Studs

Due to taper

- Increased beam spread useful for detection.
- Lower frequency, or smaller diameter probe.
    - e.g. 3.5 MHz, 12 mm Evident V182-RM
- Use of low angle longitudinal waves @ 10º also very useful.
- Lots of reference samples

Summary

- Understand the likely mode of failure
- Know the history
    - If in doubt, ask!
- No single probe will be perfect for all components
- May need multiple probes
- Standards for testing as manufactured forgings e.g AS 1065 are not suitable for in-service discontinuities
- You will need a procedure
- You may need a component specific procedure
- To ensure effective future monitoring, ensure you have collected sufficient information for reproducible re-inspections
- You will need a procedure!
- Before making that big call, get a 2nd opinion