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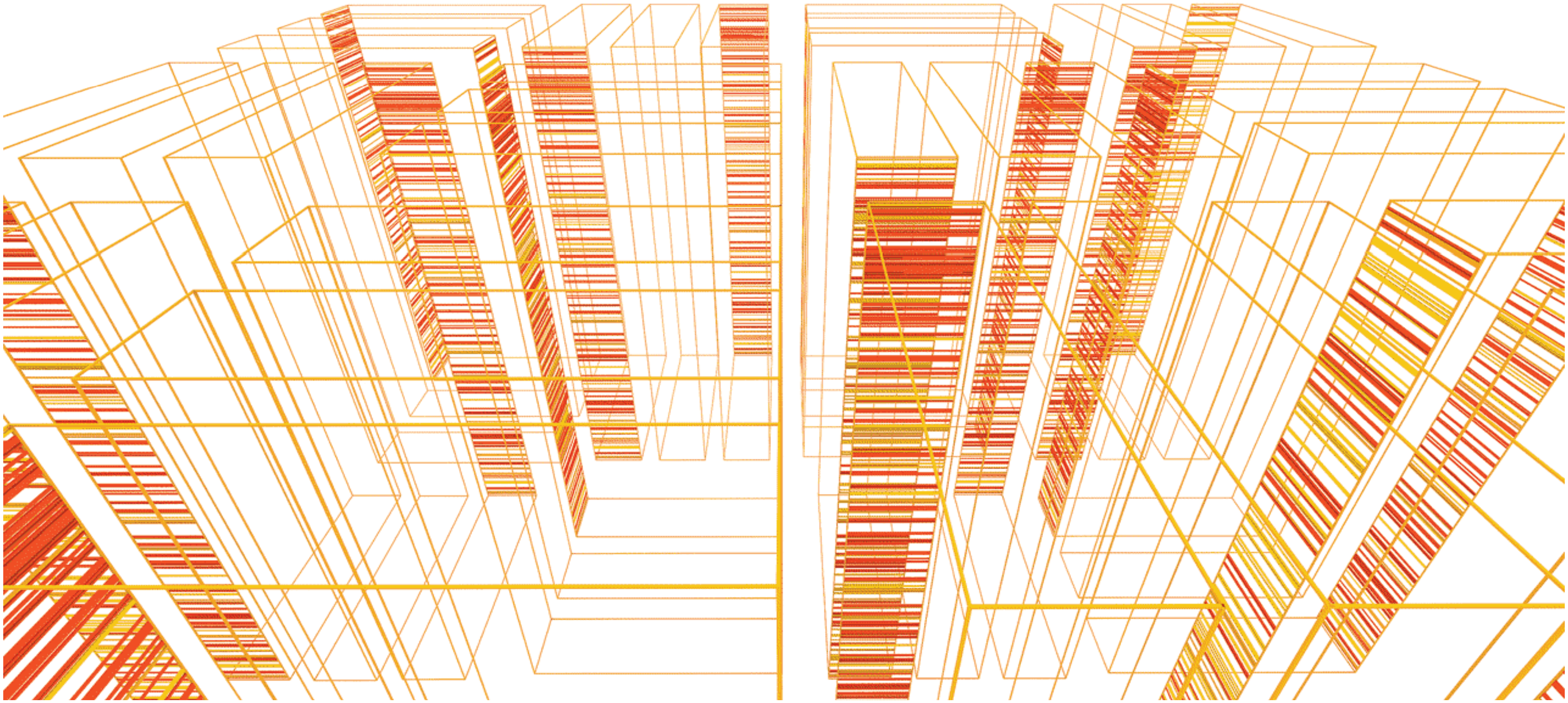

DOT PHMSA Weld Seam Quality Workshop - What is the Nature and Extent of the Issue?

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Presentation Summary

- Seam weld failure incident history
- Reports of weld failure incident history
- Reported ERW weld seam failure causes
- ERW weld seam defect causes
- ERW Manufacturing overview
- ERW weld seam quality improvements
- ERW weld seam quality QA/QC

Seam weld failure incident history

- As an industry pipe manufacturers do not collect and compile data of weld seam failures
- Individual manufacturers are not consistently notified of weld failures in the product.

Reports or publically available data

1-3: Summary of US ERW failures (< 1989)

- US DOT and DOC reports on performance of ERW failures before 1989

4-5: Background data from US ERW failures

- General papers on integrity assessments of ERW pipe

6-7: Alberta EUB – Alberta pipeline performance (1990-2005)

- Alberta Energy and Utilities Board report breaks out weld failures but does not differentiate seam, girth or other welds

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Reports or publically available data

1. R. J. Fields, E. N. Pugh, D. T. Read, and J. H. Smith, An Assessment of the Performance and Reliability of Older ERW Pipe lines, *U.S. Department of Commerce, National Institute of Standards and Technology, NISTIR 89-4136*, Gaithersburg, MD, 1989.
2. U.S. Department of Transportation, Research and Special Program Administration, Pipeline Statistics, October 1983.
3. U.S. Department of Transportation, Research and Special Program Administration, Electrical Resistance Weld Pipe Failures on Hazardous Liquid and Gas Transmission Pipelines, *Draft Report*, June 1989.
4. J. F. Kiefner, Dealing with Low-Frequency Welded ERW Pipe and Flash-Welded Pipe with Respect to HCA Related Integrity Assessments, ASME Engineering Technology Conference on Energy – ETCE 2002/Pipe-29029, Houston, TX, 2002.
5. M. Rusin and E. Savvides-Gellerson, The Safety of Interstate Liquid Pipeline: An Evaluation of present levels and Proposals for Change, American Petroleum Institute Research Study # 040, July 1987.
6. Alberta Energy and Utilities Board, Report 2007-A: Pipeline Performance in Alberta, 1990-2005, April 2007
7. Alberta Energy and Utilities Board, Statistical Series (ST) 2004-57: Field Surveillance Provincial Summary, January-December 2003, April 2004.

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Historical Data of US Incidents

ERW seam failures per year in hazardous liquid / natural gas pipelines (1968 – 1988) classified by the decade of construction [1, 3]

Event year	1920s	1930s	1940s	1950s	1960s	1970s	1980s	Unknown	Totals
1968	-/1	-/4	-/1	-/8	-/10				-/24
1969	-/1	-/3	-/3	-/2	-/9				-/18
1970		-/3	-/3	3/7	-/3	1/-			4/16
1971		1/-	-/1	5/3	3/9				9/13
1972			4/1	1/10	1/3			1/-	7/14
1973		-/1	1/2	8/2	1/2	1/-			11/7
1974		3/-	4/3	4/2	-/4				11/9
1975			2/1	-/1	-/5	-/1			2/8
1976		1/-	2/2	-/4	1/5			1/-	5/11
1977			3/1	2/5	1/1				6/7
1978			2/2	4/3	-/2	1/-		3/1	10/8
1979		1/-	3/1	1/2	1/1	-/1		1/-	7/5
1980			1/-	-/2	1/1				2/3
1981			-/-	1/1	5/1			1/-	7/2
1982			2/-	2/1	-/1	-/1		1/-	5/3
1983			1/-	2/1	1/-			1/-	5/1
1984			2/1	-/3					2/4
1985			1/-	1/-	-/1				2/1
1986				6/3	-/2	2/-			8/5
1987			-/1	-/1	-/5				-/7
1988				-/3	-/2			1	-/6
HL/NG	-/2	6/11	27/23	40/64	15/67	5/3	0	9/2	103/172
Total	2	17	50	104	82	8	0	11	275

- Most of US weld seam failures between 1968-1988 were related to pipe built in 1960's and earlier.

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Historical Data of Alberta Incidents

All weld-related failure (leaks and rupture) per year in Alberta hazardous liquids and natural gas pipelines [7]

Year	Total Failure	Weld Failure	Fraction Weld Failure
1990	792	39	
1991	740	31	
1992	737	32	4.2%
1993	714	30	
1994	792	26	
1995	688	26	
1996	780	22	
1997	753	34	3.2%
1998	782	26	
1999	870	17	
2000	842	31	
2001	779	31	
2002	717	18	3.1%
2003	684	14	
2004	722	18	
2005	799	27	
Total	12,191	422	3.5%

- There is a trend down in the fraction of weld (seam, girth, and other) failures between 1990 and 2005 in Alberta

Note: weld failures include seam, girth and other weld problems.

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Historical Data of US Pipe Use

Mileages of US interstate hazardous liquid pipelines in ~1987 classified by type of pipe [1,4]

	Miles (%)
Pre – 1970 ERW	46,217 (41)
New ERW	19,549 (17)
Seamless	26,555 (24)
Submerged AW	11,639 (10)
Lap Welded	3,277 (3)
Other	5,763 (5)
Total	113,000 (100)

- In ~1987, most (41% of total pipe or 71% of ERW pipe) of the pipelines in the US are from ERW pipe made prior to 1970,
- In that same year, 17% of the total pipe or 29% of the ERW pipe are from ERW pipe made after 1970.

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ERW Seam Failure Causes

Causes of US ERW seam failures in liquid transmission pipelines (1977 – 1988) based on metallurgical examinations [1, 3]

Cause of failure	Service failure	Hydrotest failure
Fatigue crack initiation for misalignment	4	-
Lack of fusion (OD)	6	24
Lack of fusion (ID)	-	8
Hook crack (ID)	4	-
Selective corrosion	6	-
Hard spot micro-cracks	2	-
Corrosion fatigue (LOF)	3	-
Fatigue at lamination in ERW seam	1	-
Total	26	32

- Between 1977 and 1988, most ERW seam failures (38 of 58) were due to lack of fusion

Primary ERW Seam Defect Causes

- **Non-Fused Weld**
  - Inconsistent or inadequate heat input
  - Inconsistent or low frequency
  - Inadequate upset
- **Penetrators**
  - Inadequate upset or heating
  - Inclusions
- **Hook Cracks**
  - Upturned inclusions on or near bond line
- **Geometric**
  - Inadequate mill set-up

ERW Manufacturing Processes

Low Frequency ERW (typically 350-450 Hz AC)

- Developed in 1929 and was primary ERW manufacturing method until 1960's
- Can cause weld "stitching" (repeated lengths of lack of fusion) due to intermittent nature of heat input.
- Sensitive to surface condition (scale, dirt, etc), contact resistance, and upset pressure
- Results in non-weld areas, low weld and heat affected zone (HAZ) strength and toughness due to extensive grain coarsening, preferential corrosion, low fatigue, and more hook cracks at inclusion stringers.

High Frequency ERW (typically 300-500 kHz AC)

- Developed in 1962 and phased out LF ERW by 1978 in US and Canada.
- Relatively insensitive to factors causing LF ERW defects producing uniform sound weld.
- Produces a narrow HAZ with limited grain coarsening – hence strong ductile weld.

ERW Weld Quality Improvements

Steel Cleanliness – inclusions and segregation

- Steelmaking - transition from Open Hearth to Basic Oxygen and Electric Arc Furnaces (from 1960's into 1980's)
  - improved oxidation and sulfide control with clean steel practices
- Ladle Metallurgy – introduction of dedicated stations (from 1980's)
  - Temperatures control - improved chemical segregation
  - Reduce quantity and control shape of inclusions (e.g. Ca) – refine inclusions to be less harmful
- Casting– transition from ingot to continuous casting (from 1980's)
  - Reduced chemical segregation
  - Reduce inclusions – Tundish design, slag detection, EMS, vacuum degassing (from 1990's)

Microstructure – strength, toughness and weldability

- Steel design – transition from as-rolled medium carbon (~0.12% C) to thermo-mechanically control rolled (TMCP) microalloyed (~0.05% C) steels (from 1980's)
  - Refined microstructure – increased strength and toughness
  - Improved weldability and HAZ toughness

Welding Process - heat input, mill set-up, post-weld cooling

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ERW Weld Quality Improvements

- Steel Cleanliness – inclusions and segregation
- Microstructure – strength, toughness and weldability
- Welding Process - heat input, mill set-up, post-weld cooling
  - Heat input –
    - Transition from LF to HF (from 1960's)
    - Power control and stability– transition from tubes to solid state power supplies
    - Tuning for optimization
  - Mill set-up -
    - Tuning edge alignment, v-angle/length, and upset
  - Weld Annealing and slow cooling
    - Mandated by API 5L (1967) – to refine and soften hard weld region
    - Annealer tracking systems (from 1990's) – improved seam tracking

ERW Weld Quality QA/QC

Mill Testing

- Hydrostatic testing
  - Mandated by API 5L (1967) – 60-90% of SMYS for 5 or 10 seconds with visual inspection for leaks during test

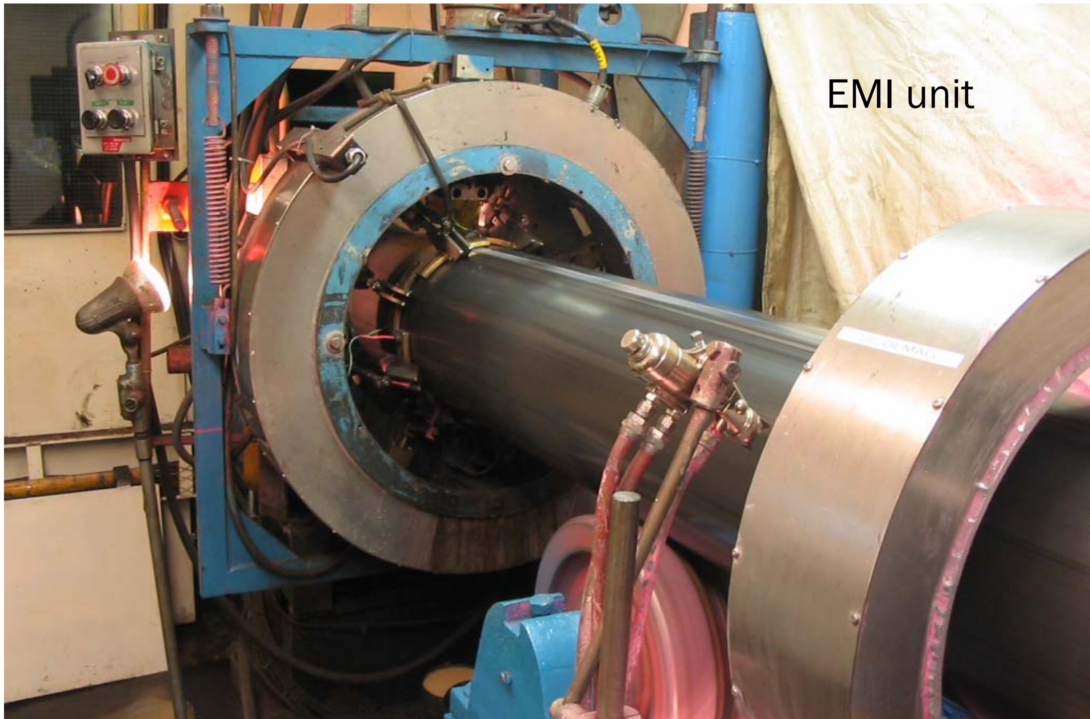
Non-Destructive Testing (NDT)

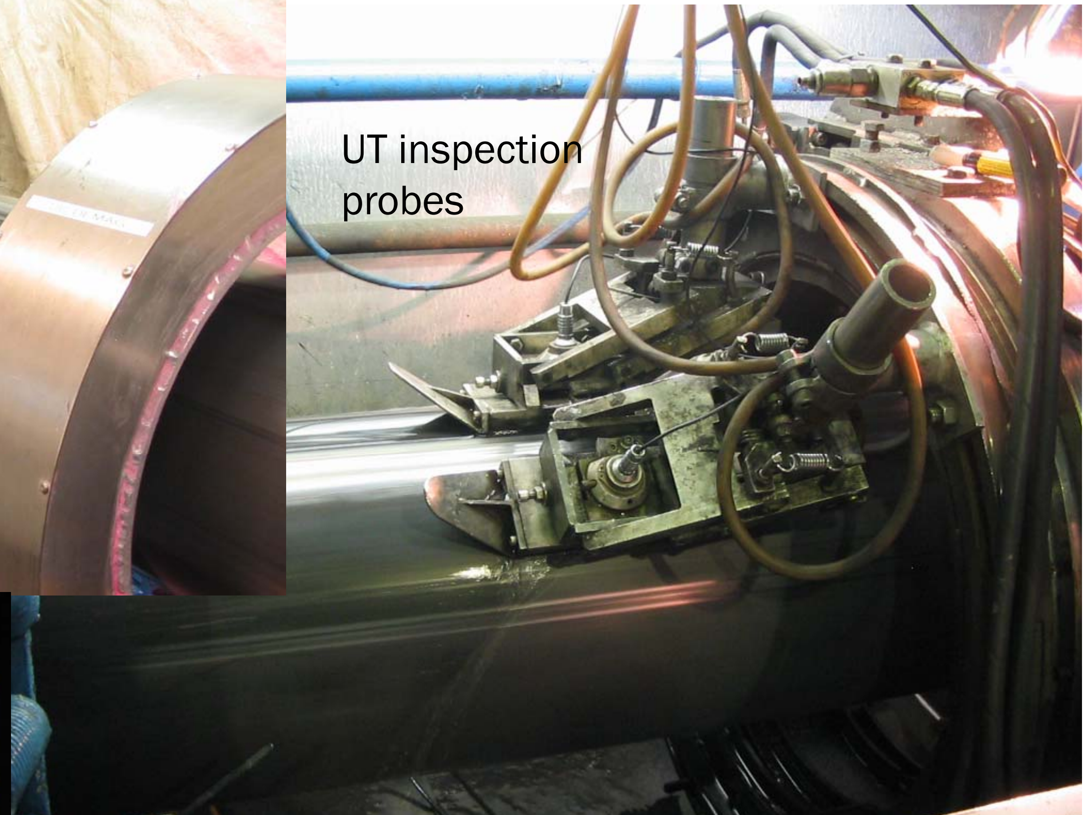
- Weld seam Ultrasonic Testing (UT) - amplitude-based
  - Mandated by API 5L (1963)
  - Standardized testing though ASTM standards
- Mill weld seam UT systems – provide welders immediate feedback on weld quality
- Supplementary NDT (e.g., electromagnetic and eddy current) systems

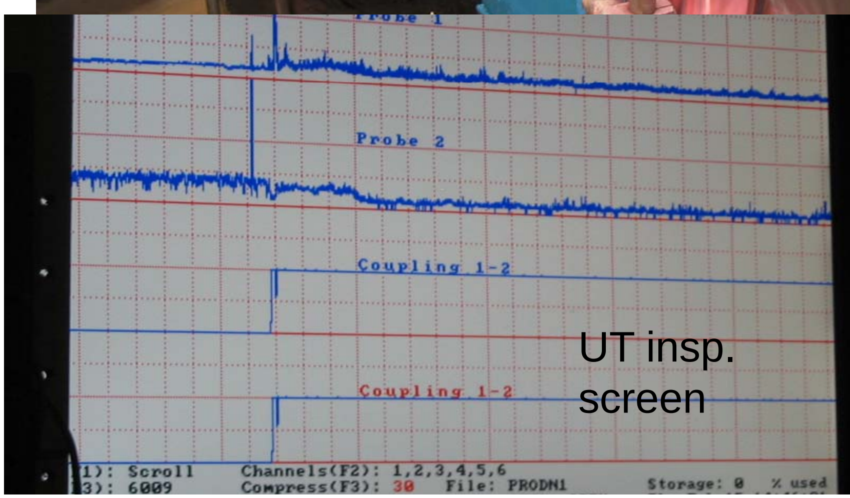
Quality Assurance (QA) Systems

- Mature systems - CSA Z299 / ISO 9001 (1980's), API Q1 (1990)
- Mandated by CSA Z245.1 (1980's?), API 5L (2012)

Non-Destructive Inspection







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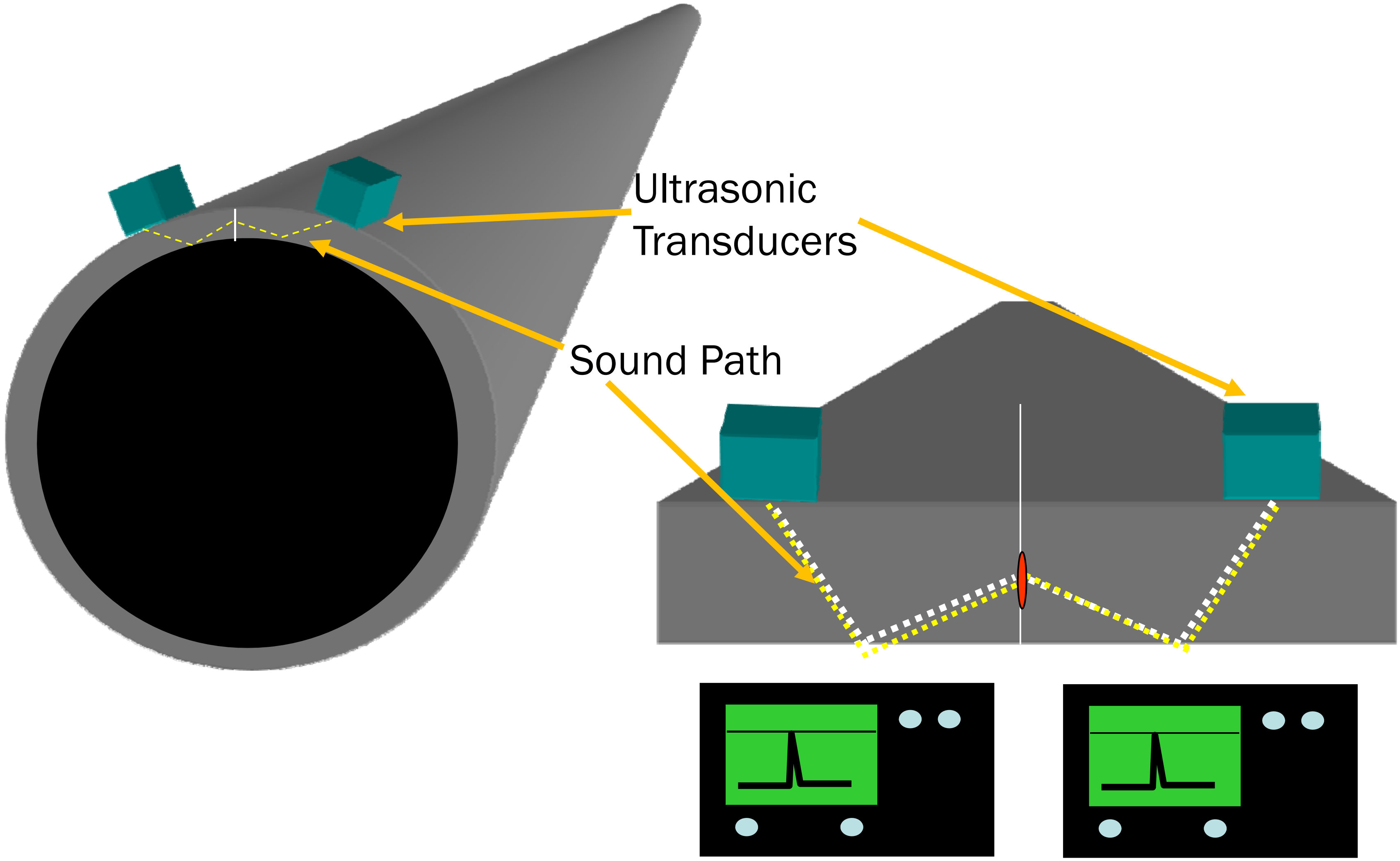
Ultrasonic Inspection



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Thanks!