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Railcar Wheels Sub-surface Defect Monitoring Using Ultrasonics

Anish Poudel, PhD

Principal Investigator – NDE

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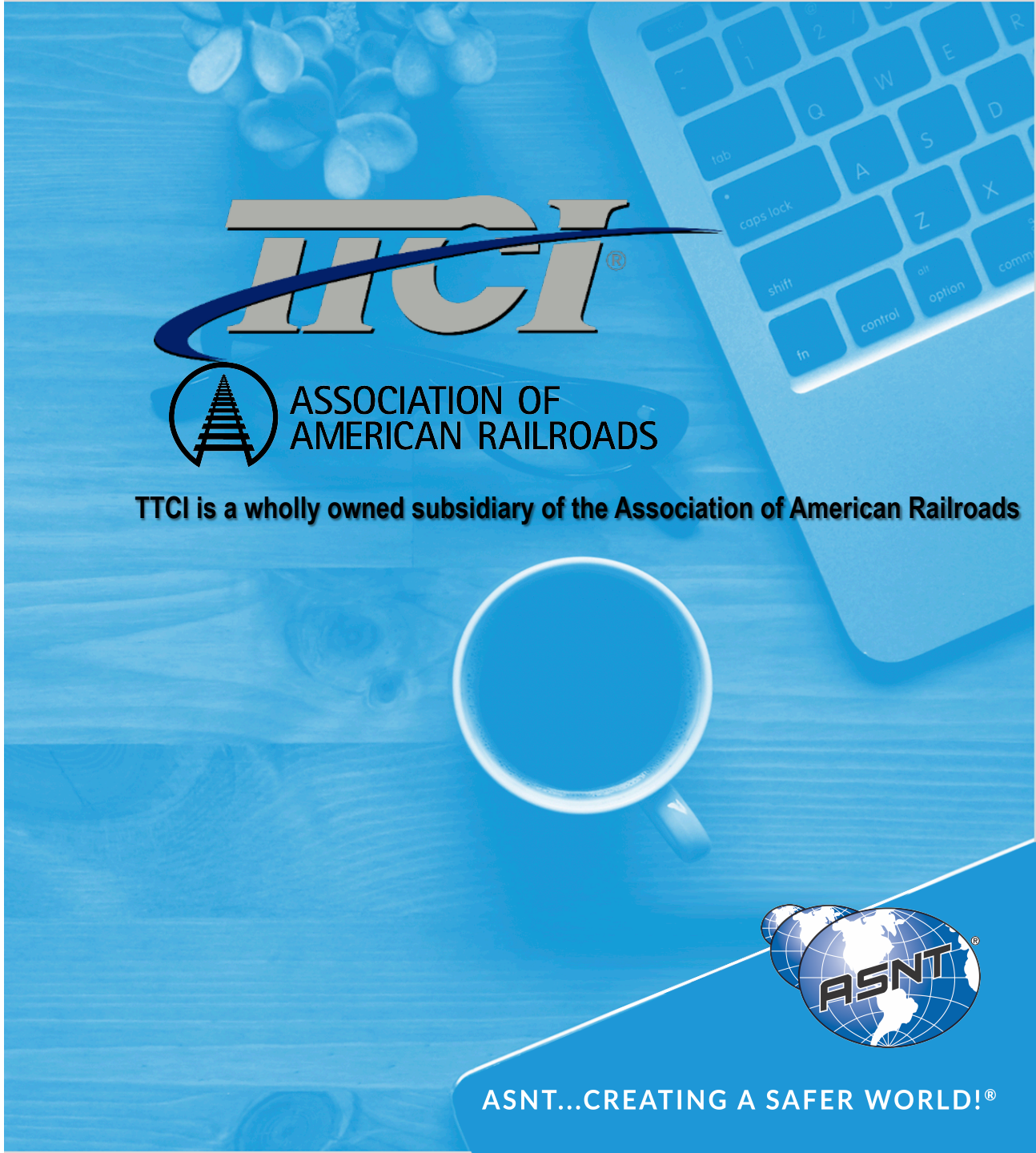

Anish Poudel, Ph.D.

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- Principal Investigator – NDE, Transportation Technology Center, Inc.
- Ph.D., Mechanical Engineering, SIUC, Carbondale, IL
- ASNT leadership positions
  - Board of Directors
  - Chairman, Research Council
  - Past-Chairman, CO Section
  - Past- Program Chair, Research Symposium
  - Chair, AI/ML Committee – Engineering Council
- Awards & Honors
  - IHHA Emerging Railway Professionals Award, 2019
  - ASNT Mentoring Award, 2018
  - ASNT Young NDT Professional Award, 2014
  - SIU Richard and Donna Falvo Outstanding Dissertation Award, 2015
  - SIU Alumni Association Outstanding Master's Thesis Award, 2011
- Representing USA/ASNT in Global Ambassadors on NDE 4.0
- 100+ peer-reviewed publications
- 1 Patent

Presentation Outline

- TTCI/AAR Overview
- Introduction – North American Railroads
- Background – Broken Wheels
- Automated Cracked Wheel Detector System (ACWDS)
- Ultrasonic Testing (UT) Principle
- ACWDS Ultrasonic Output Results
- ACWDS Operation
- Facility for Accelerated Service Testing (FAST)
- ACWDS Recent Findings
- Conclusions
- Acknowledgements

AAR/TTCI

- The Association of American Railroads (AAR) is an industry trade group representing primarily the major freight railroads of North America, Amtrak and some regional commuter railroads
  - Founded in 1934
  - Headquartered in Washington, D.C.
  - Major Areas of focus includes Policy making, Standard setting, Industry data, reports and publications, and Research and technology initiatives
- TTCI is a wholly owned subsidiary of the AAR
  - Operated by an on-site management team
  - Guided by an independent Board of Directors
  - Generally, the COO of each Class I railroad

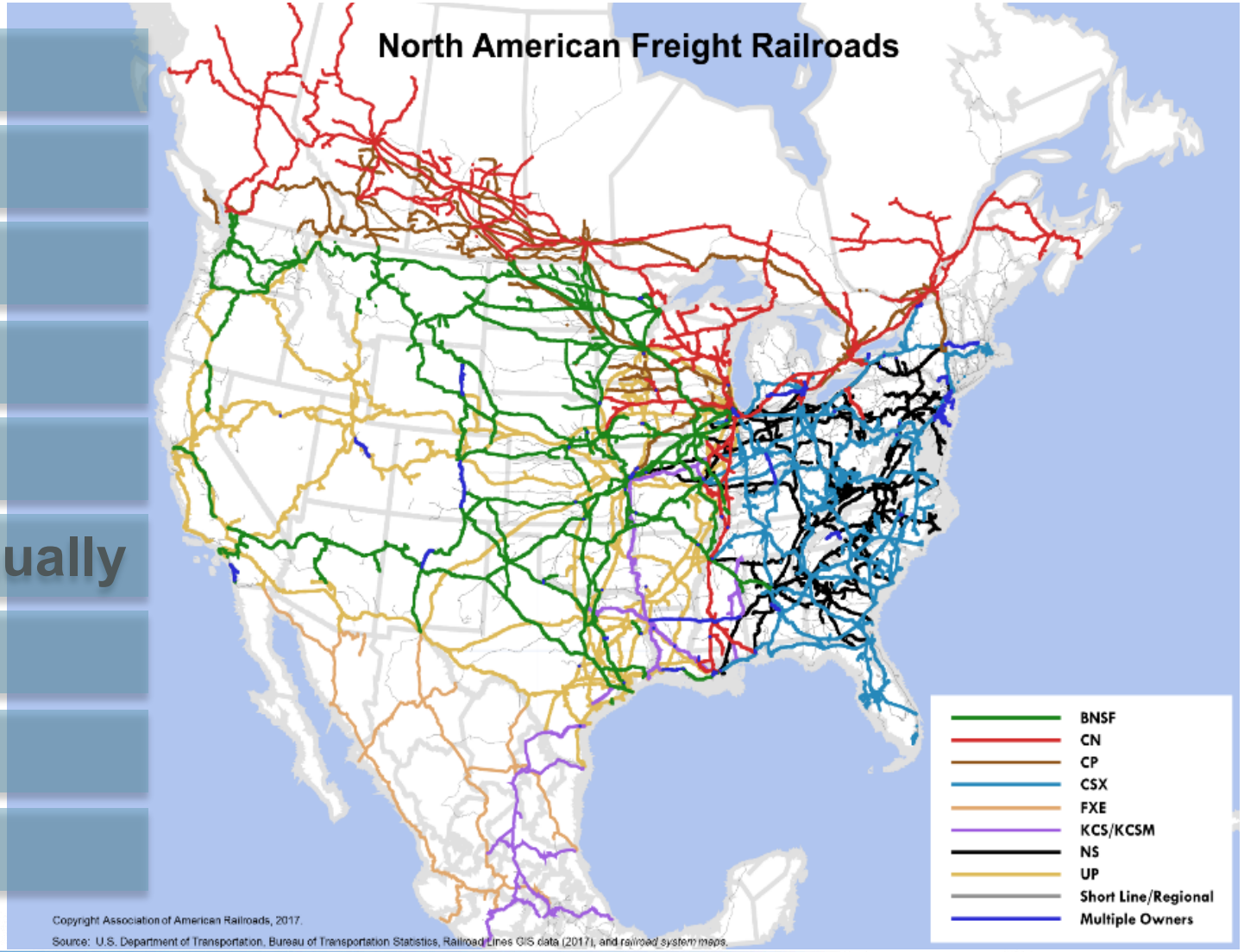
ASSOCIATION OF AMERICAN RAILROADS

TTCI®

A Small Business Enterprise

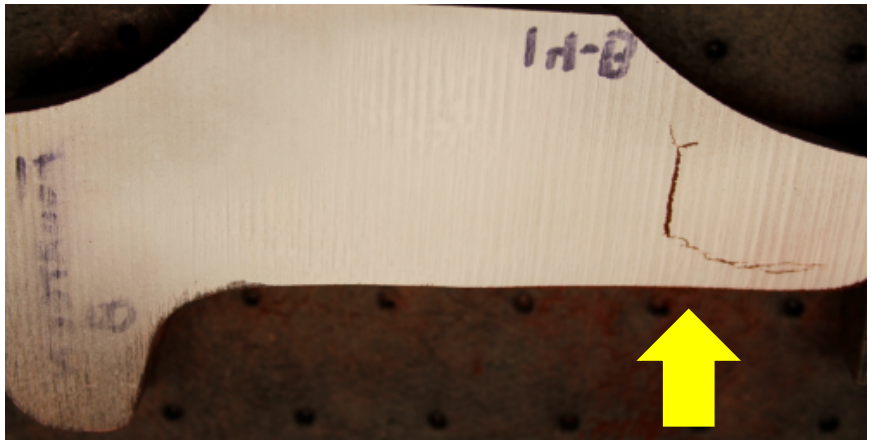
North American Freight Railroads

- 650 separate railroads; 7 Class I
- 1.6 million freight wagons
- 180,000 miles of track
- 167,000 employees
- 32.5-tonne axle loads allowed
- 1.47 billion tonnes of freight annually
- 32 million passengers annually
- 30,000 locomotives
- $70 billion USD annual revenue



Why Wheel Inspection Research?

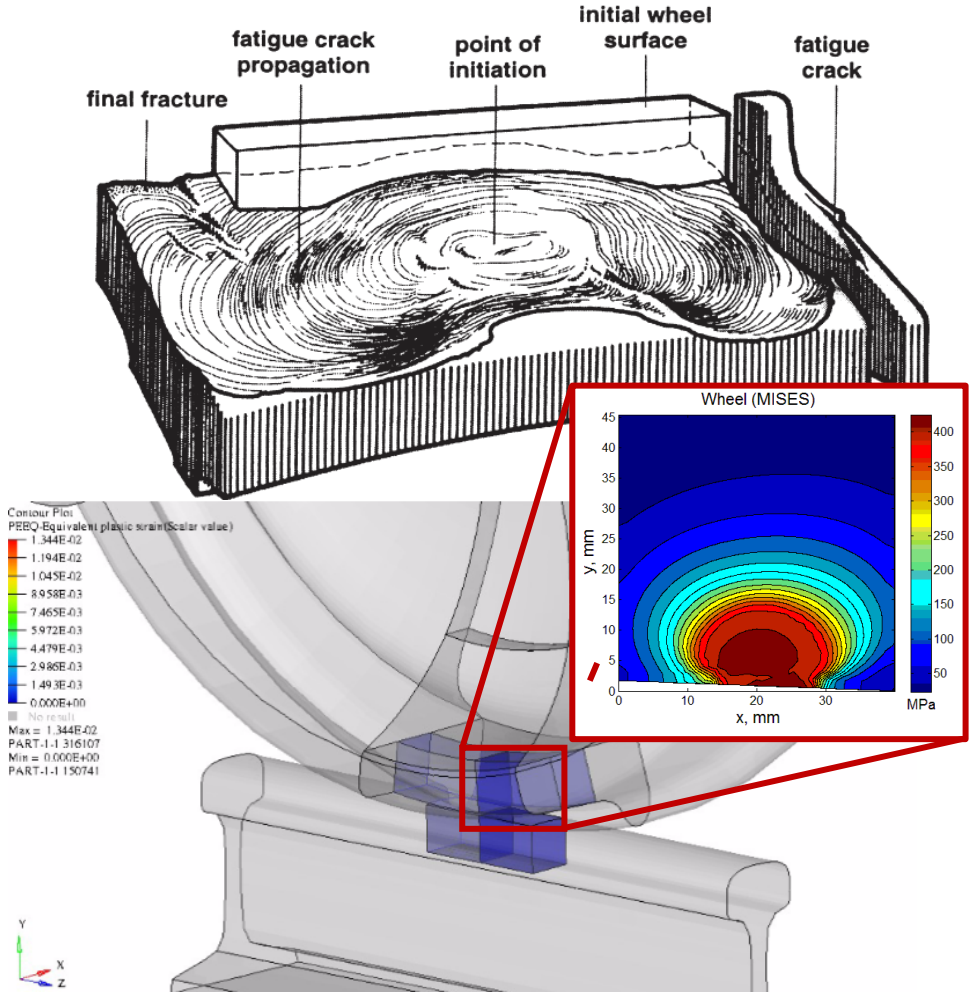
- Broken wheels are rare but important to find.
- A major precursor to wheel failure in Heavy Axle Load (HAL) service is attributed to sub-surface fatigue cracks initiating and propagating from internal discontinuities such as voids, inclusions, and micro-cracks.
- These fatigue cracks typically initiate at the depth of the maximum shear stress (approximately 3 mm - 6 mm)
- Safely detecting internal defects on wheels before they become problematic, and without interrupting service, is the goal.



Sub-surface Fatigue Crack Features

- Sketch of a fatigue crack which nucleated about 4 mm below the surface. Maximum depth of the crack below the wheel tread is about 14 mm

1. No sign of inclusions or voids at the point of initiation
2. Crack initiates at a depth of 3-10 mm below the wheel tread
3. Crack propagates in an angle downward to a depth of about 20 mm
4. Final fracture toward the surface

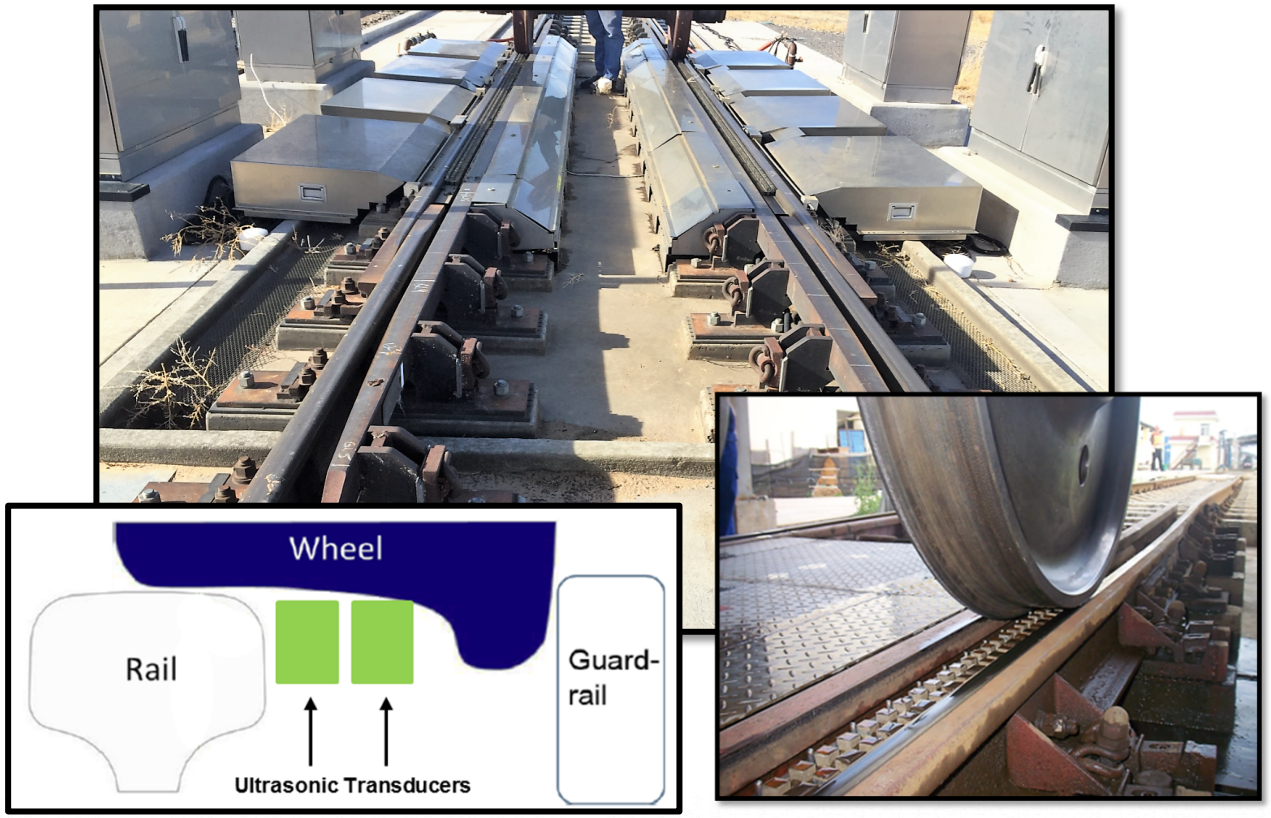


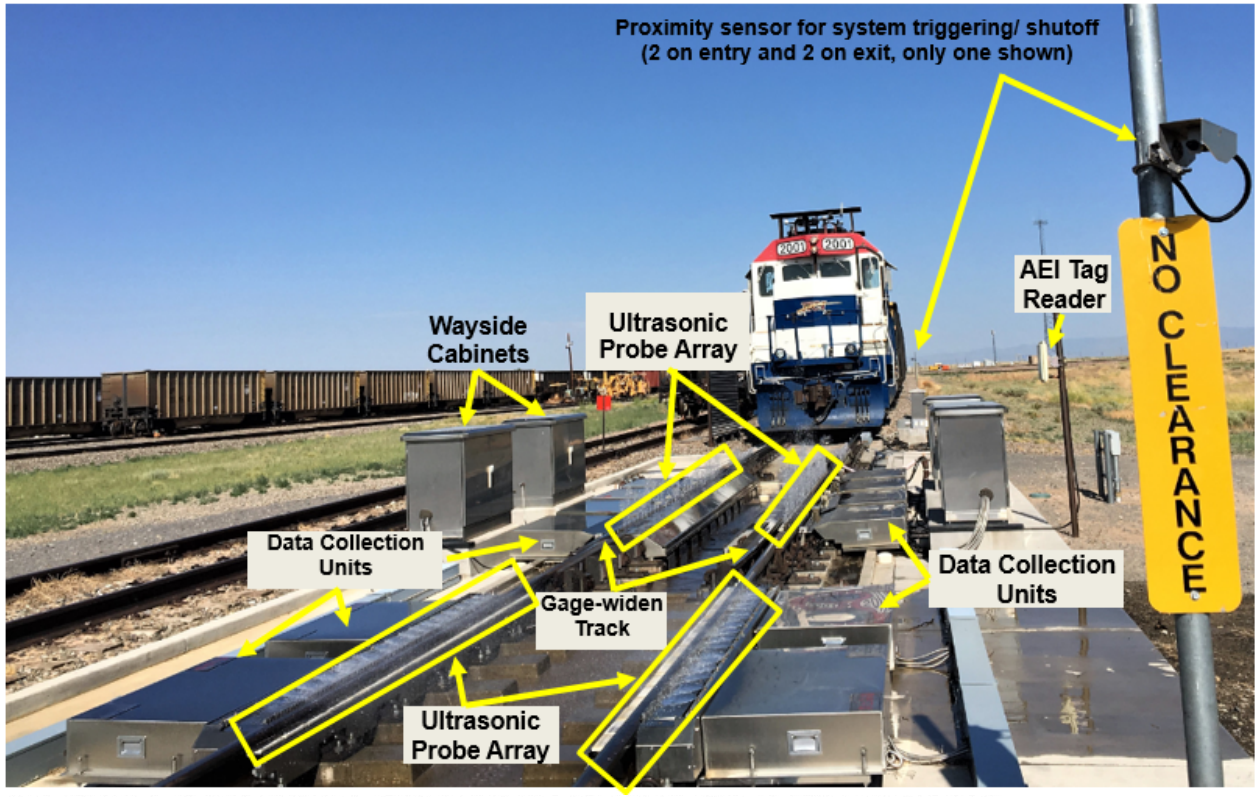
Wheel Rail Contact Stresses

Kiani, M. and Fry, G.T., 2017, "Fatigue analysis of railway wheel using a multiaxial strain-based critical-plane index," Fatigue Fract Eng Mater Struct., pp.1–13.

ACWDS

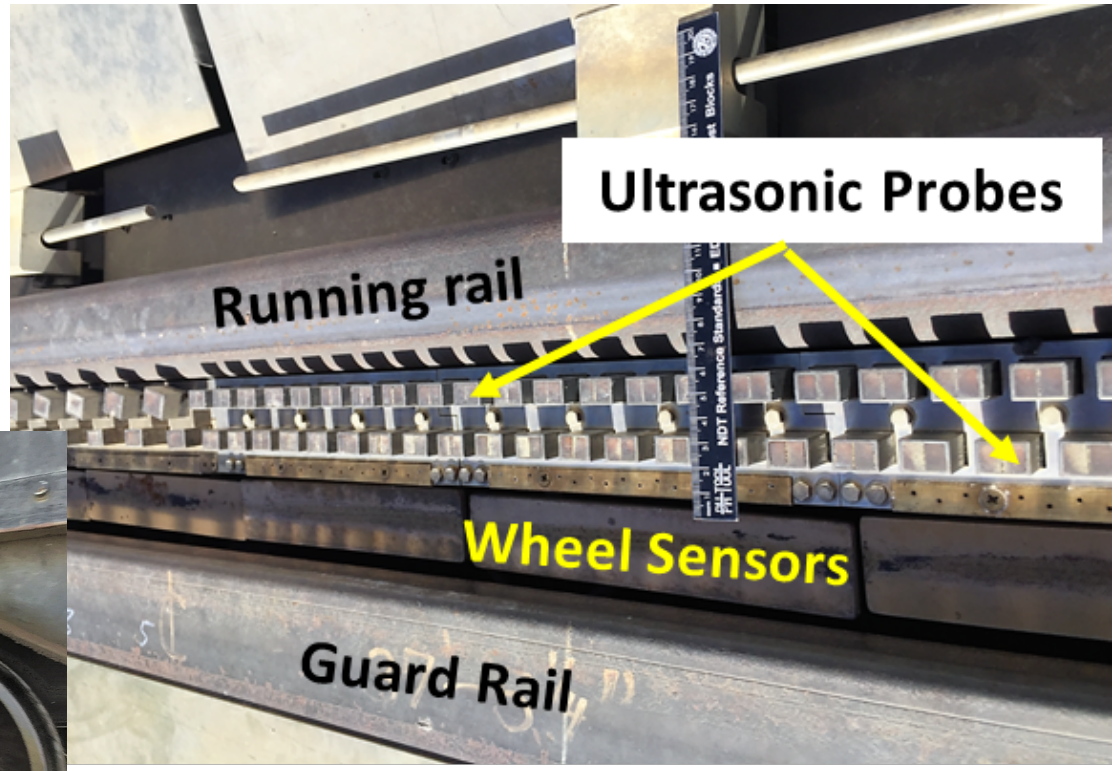
- Technology belongs to Nanjing Tycho company (China)
- Wayside NDE system for inspecting internal cracks on a moving train





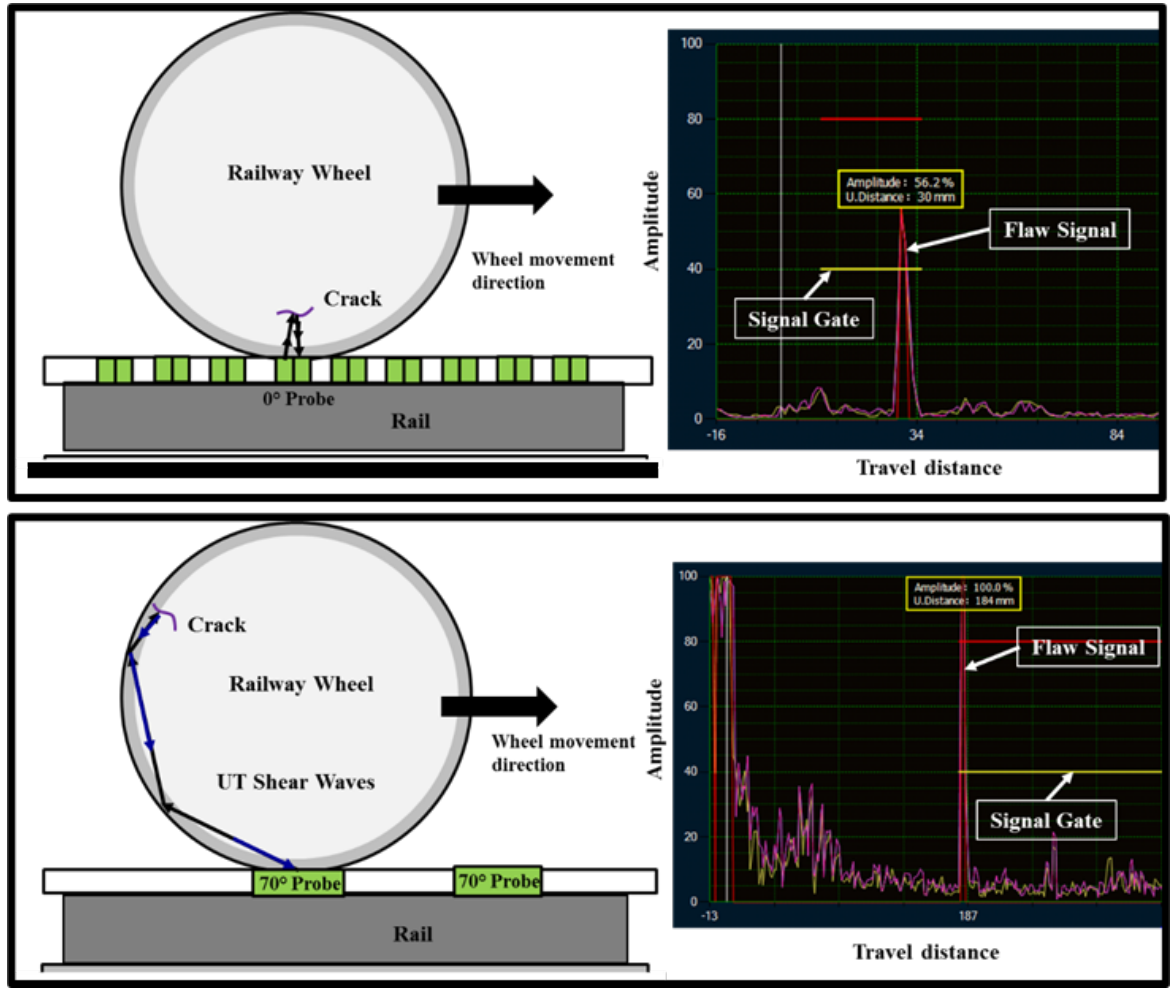
Ultrasonics Hardware Configuration

- Array of Spring-loaded ultrasonic probes
  - 0° UT probes look straight up and detects circumferential cracks
  - 70° UT probes inspect rim face and flange
- Water-based couplant sprayed through nozzles

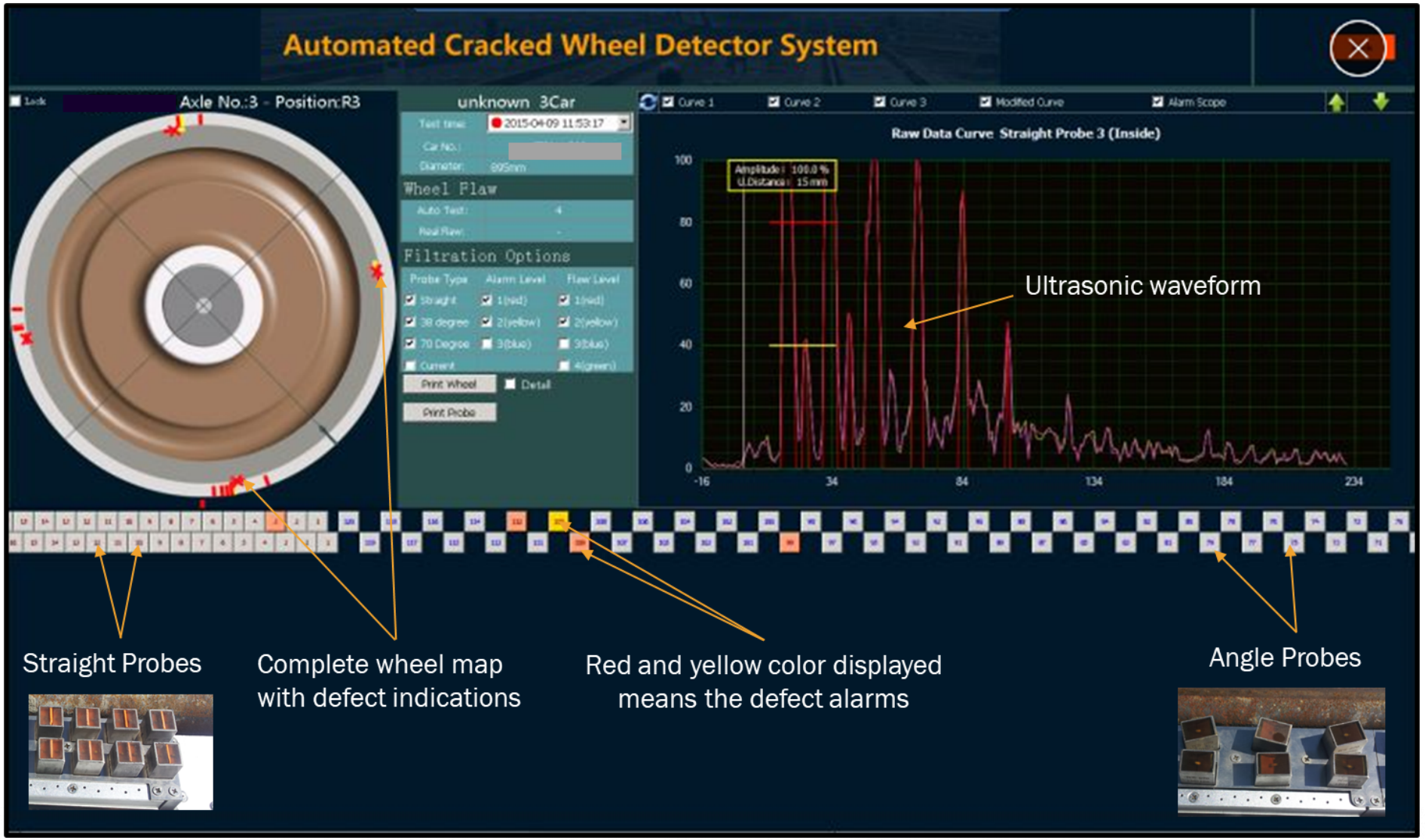


UT Principle

- 0° probes look straight up into the tread and look for the cracks running parallel to the tread surface (circumferential cracks)
- 70° probes inspect rim face and flange to detect cracks oriented in the radial direction
- These probes connect to a central computer, which runs the software program for analyzing wheel inspection ultrasonic signals.

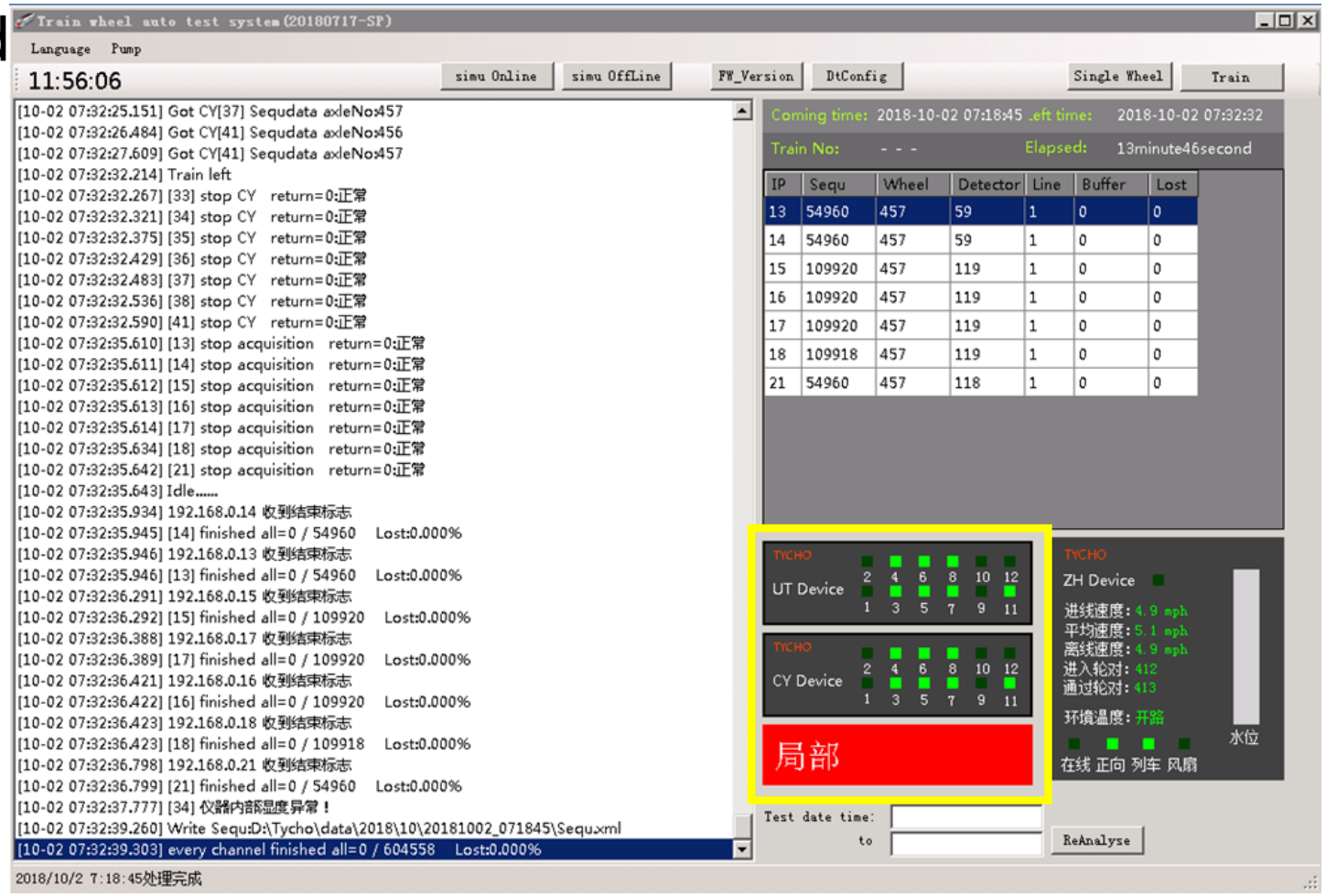


ACWDS Ultrasonics Results Output



ACWDS Operation

- System operation is automated
  - Self calibration
  - Internal self-check
  - Automated reporting
- Results available within 10 minutes
- Reporting is configurable
  - Defect alarm level (severity and confidence)
  - Reporting method (manual review, email alerts, sending alarms)

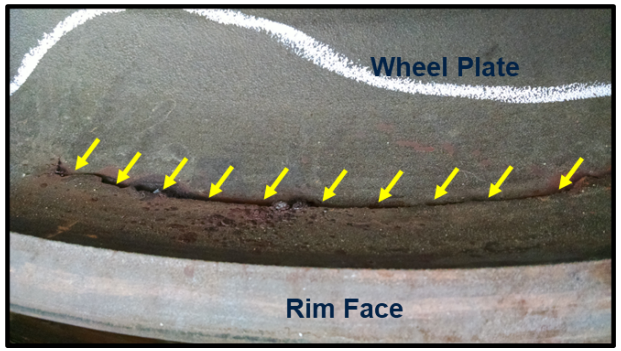


ACWDS Performance Testing

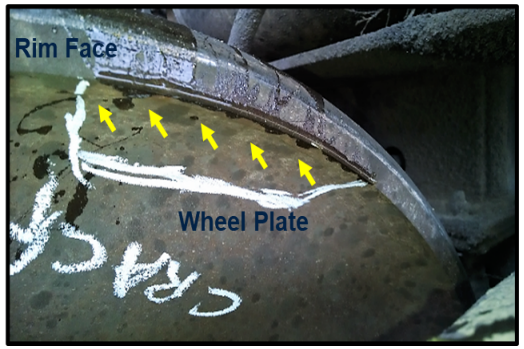
Defect Type	5 mph			10 mph			12 mph			15 mph		
	HITS	MISSES	Detection %	HITS	MISSES	Detection %	HITS	MISSES	Detection %	HITS	MISSES	Detection %
Broken Wheel # 1	15	0	100%	15	0	100%	15	0	100%	15	0	100%
Broken Wheel # 2	2	13	13%	1	14	7%	2	13	13%	1	14	7%
Broken Wheel # 3	15	0	100%	14	1	93%	13	2	87%	11	4	73%
Broken Wheel # 4	15	0	100%	15	0	100%	15	0	100%	15	0	100%
FALSE CALL	0			0			0			1		

Broken Wheel # 1

Broken Wheel # 2



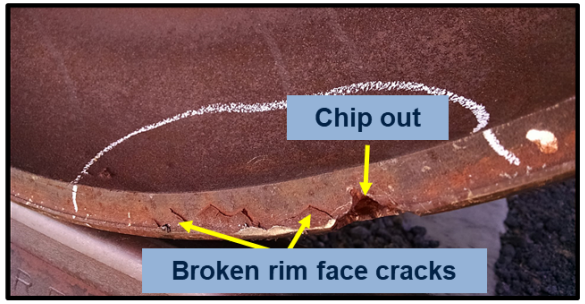
Broken Wheel # 3



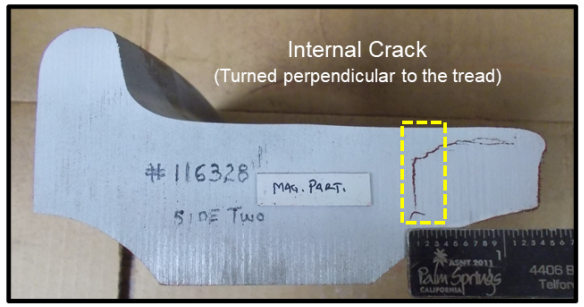
Broken Wheel # 4

ACWDS Detection Performance Verification

- Broken Wheel # 2: Detected 7% at 15 mph

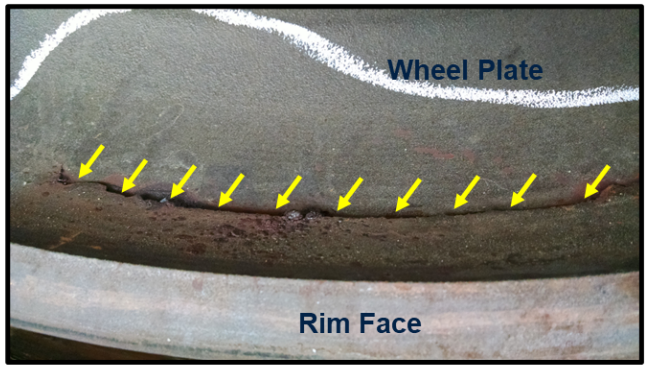


Broken Wheel # 2

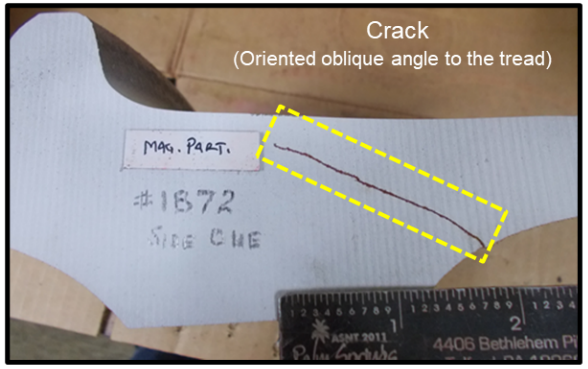


Wheel Cut Open

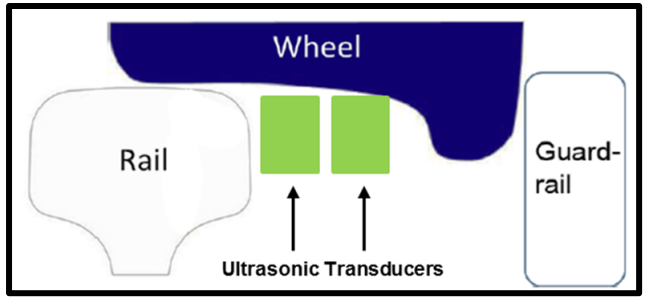
- Broken Wheel # 3: Detected 73% at 15 mph



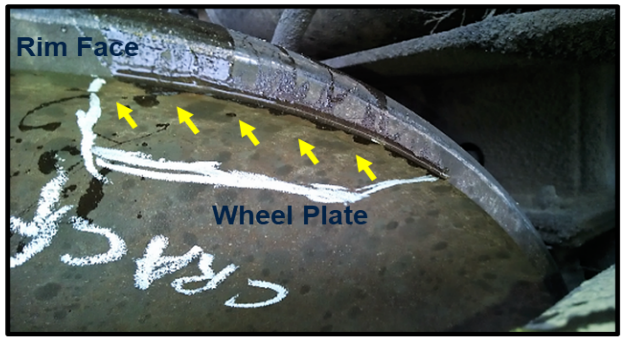
Broken Wheel # 3



Wheel Cut Open



- Broken Wheel # 4: Detected 100% at 15 mph



Broken Wheel # 4

Wheel Cut Open

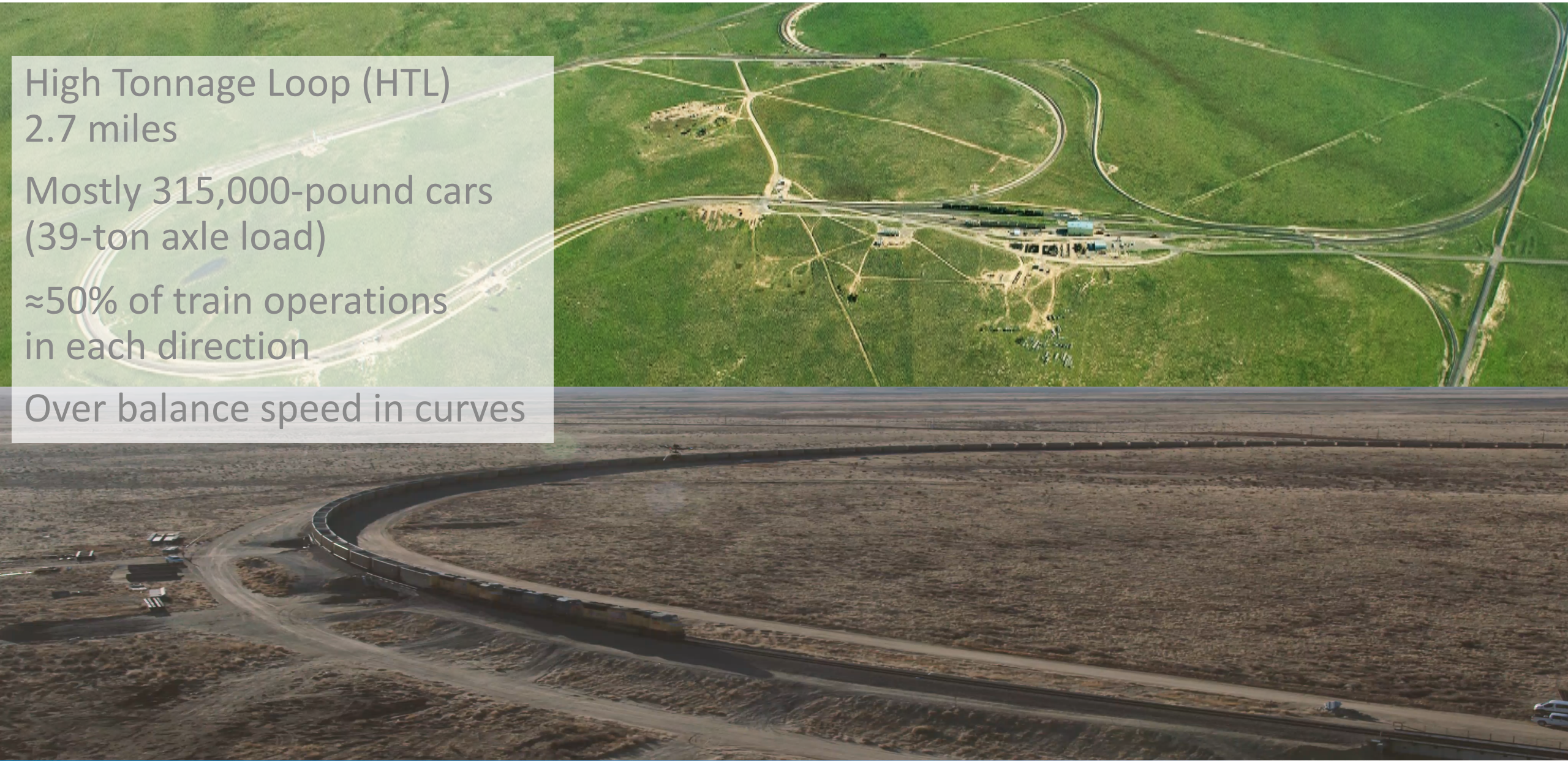
Flaw shape, size, location, and orientation governs the UT detection!

ACWDS Outward Probes

- Outboard probes added later to finds sub-surface fatigue cracks outboard of tapeline

ACWDS Demonstration

TTCI FAST Operation



High Tonnage Loop (HTL)
2.7 miles

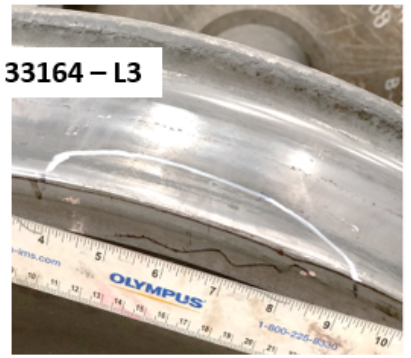
Mostly 315,000-pound cars
(39-ton axle load)

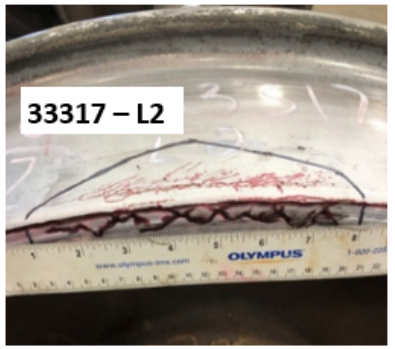
≈50% of train operations
in each direction

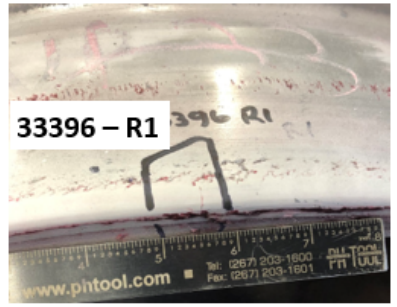
Over balance speed in curves

FAST HAL Train – 2020 Broken Wheel Removals

Car position	Car No.	Wheel position alarmed	FAST mileage (miles)	Transducer alarmed	Hand UT verification results
71	33150	R3	201,751	0° outboard	3.2-inch x 1.5-inch x 0.5-inch
62	33395	R3	219,281	0° outboard 0° wide gage	3.25-inch x 2.75-inch
7	33166	L2	138,761	0° outboard	3.4-inch x 1.1-inch x 0.2-0.4-inch
17	33396	R1	194,466	0° outboard	1.0-inch x 1.2-inch x 0.25-inch
88	33317	L2	162,145	0° outboard	7.0-inch x 1.8-inch x 0.3-inch
58	33164	L3	156,027	0° outboard	5.25-inch x 1.5-inch x 0.2-0.7-inch
72	33290	L2	56,829	0° outboard	3.5-inch x 0.9-inch x 0.3-inch

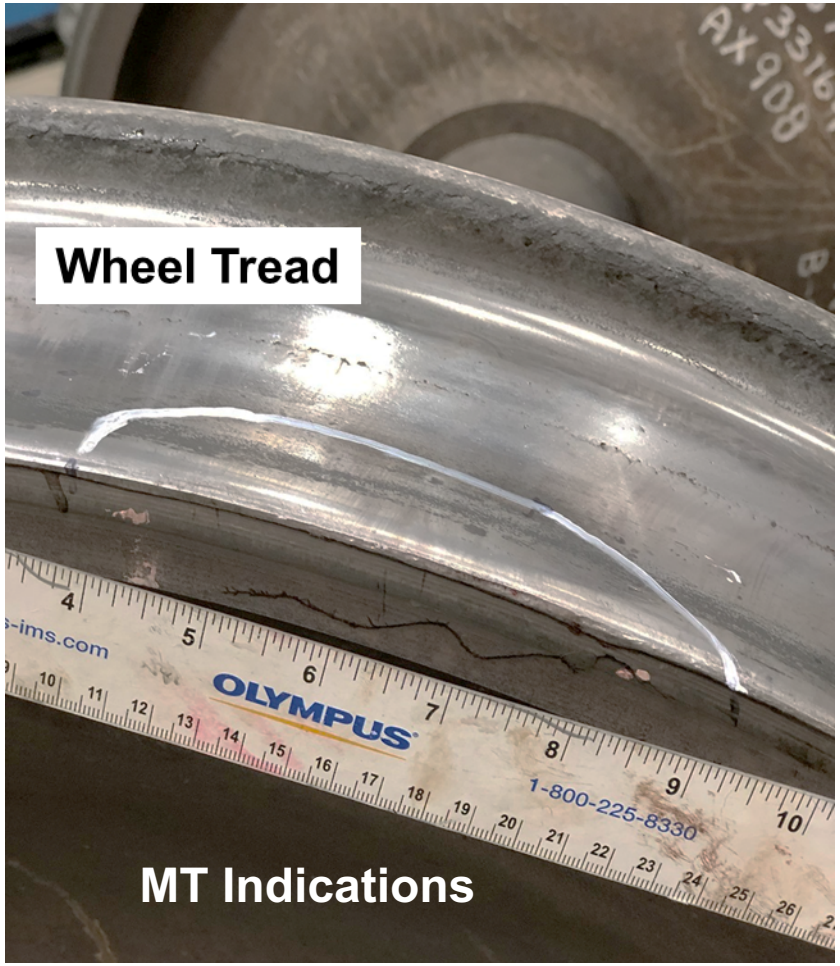


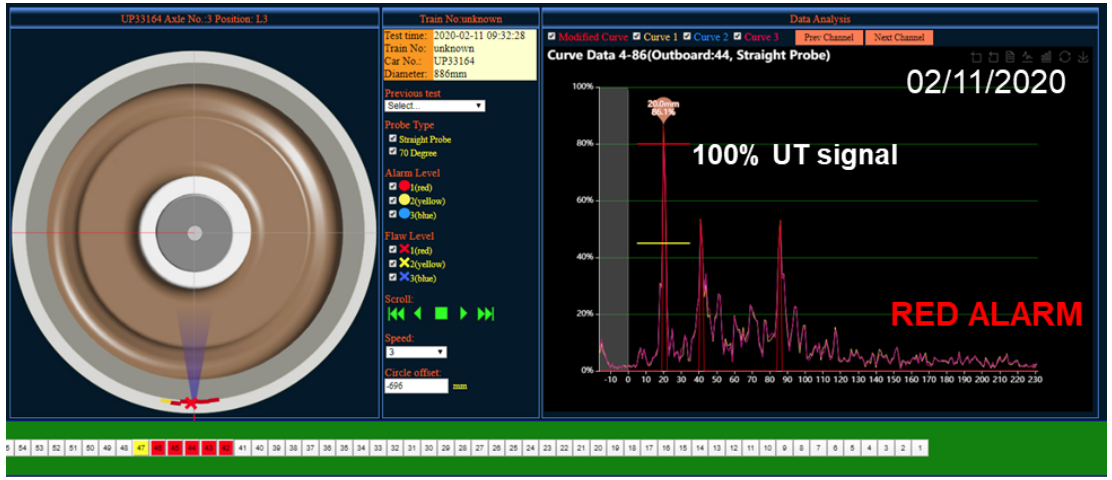




FAST Car 33164 Wheel L3

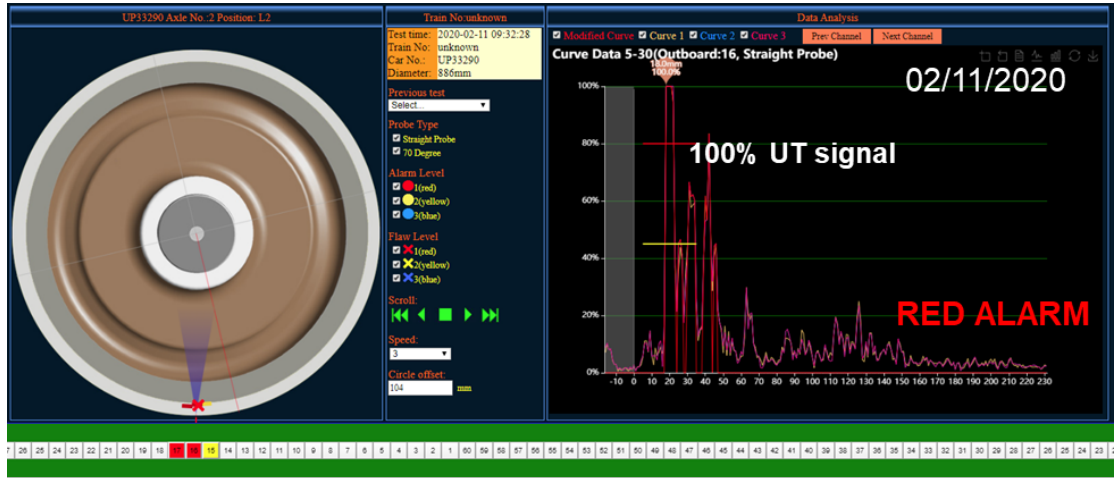
- Detected by 0° outboard probes
- Hand-UT Verification
  - 5.25-inch (L) x 1.5-inch (W) x 0.2-0.7-inch (D)

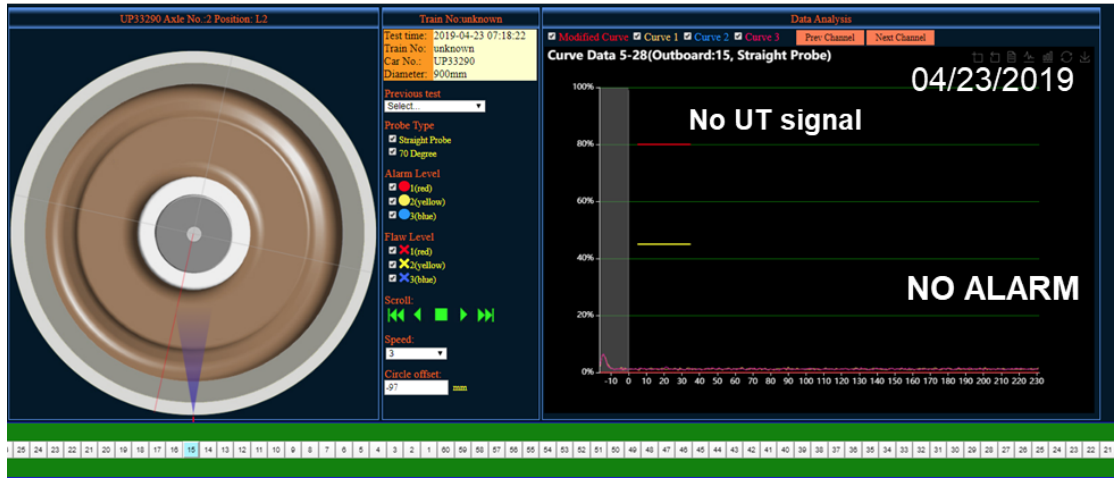




FAST Car 33290 Wheel L2

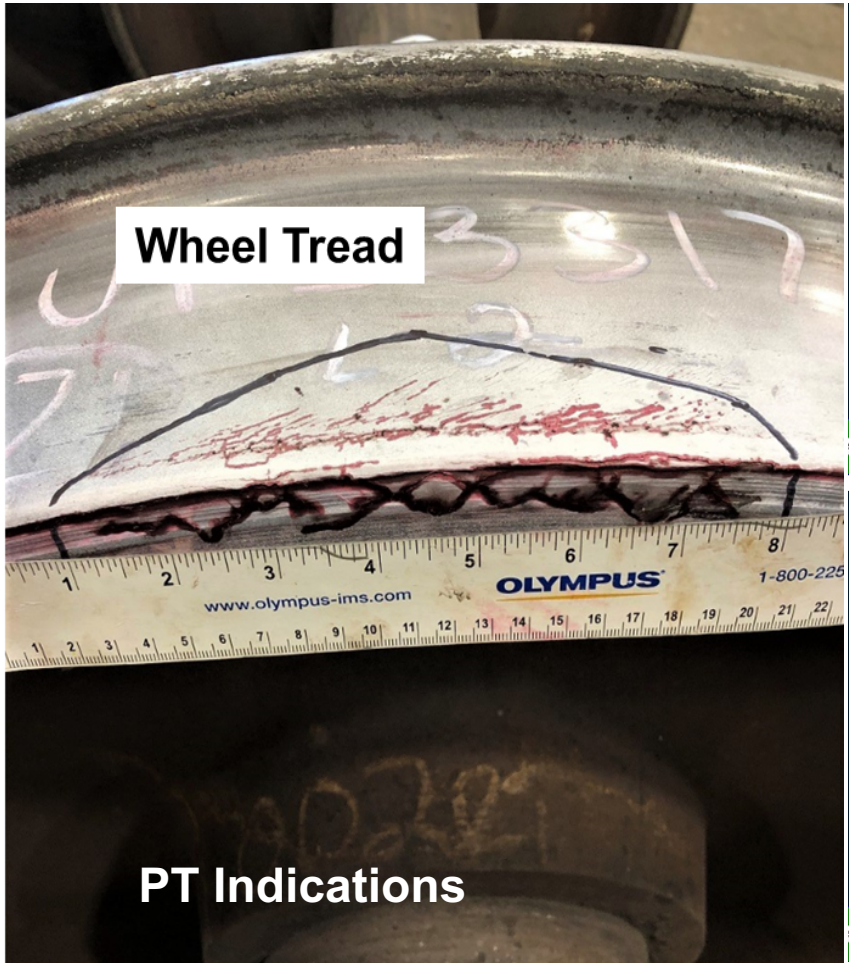
- Detected by 0° outboard probes
- Hand-UT Verification
  - 3.5-inch (L) x 0.9-inch (W) x 0.3-inch (D)

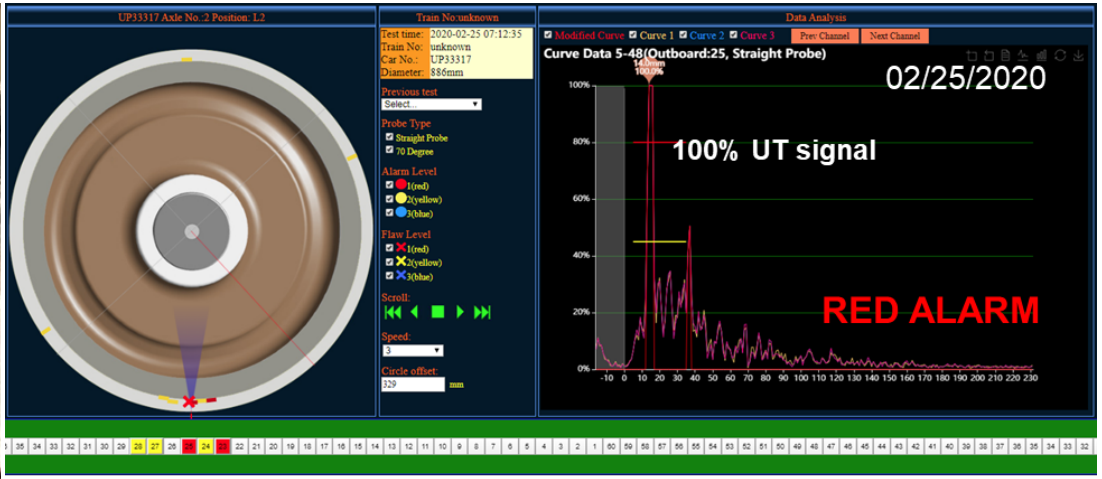


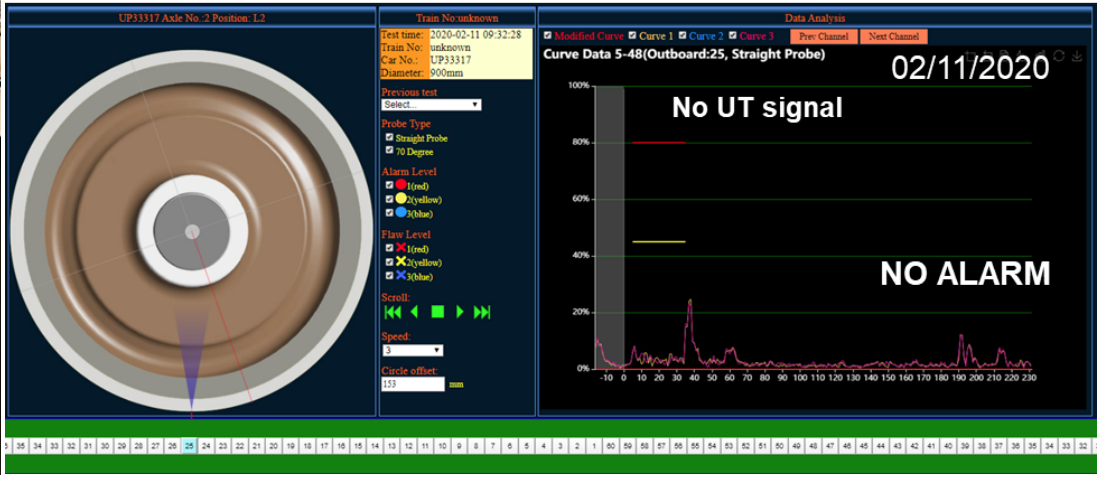


FAST Car 33317 Wheel L2

- Detected by 0° outboard probes
- Hand-UT Verification
  - 7.0-inch (L) x 1.8-inch (W) x 0.3-inch (D)



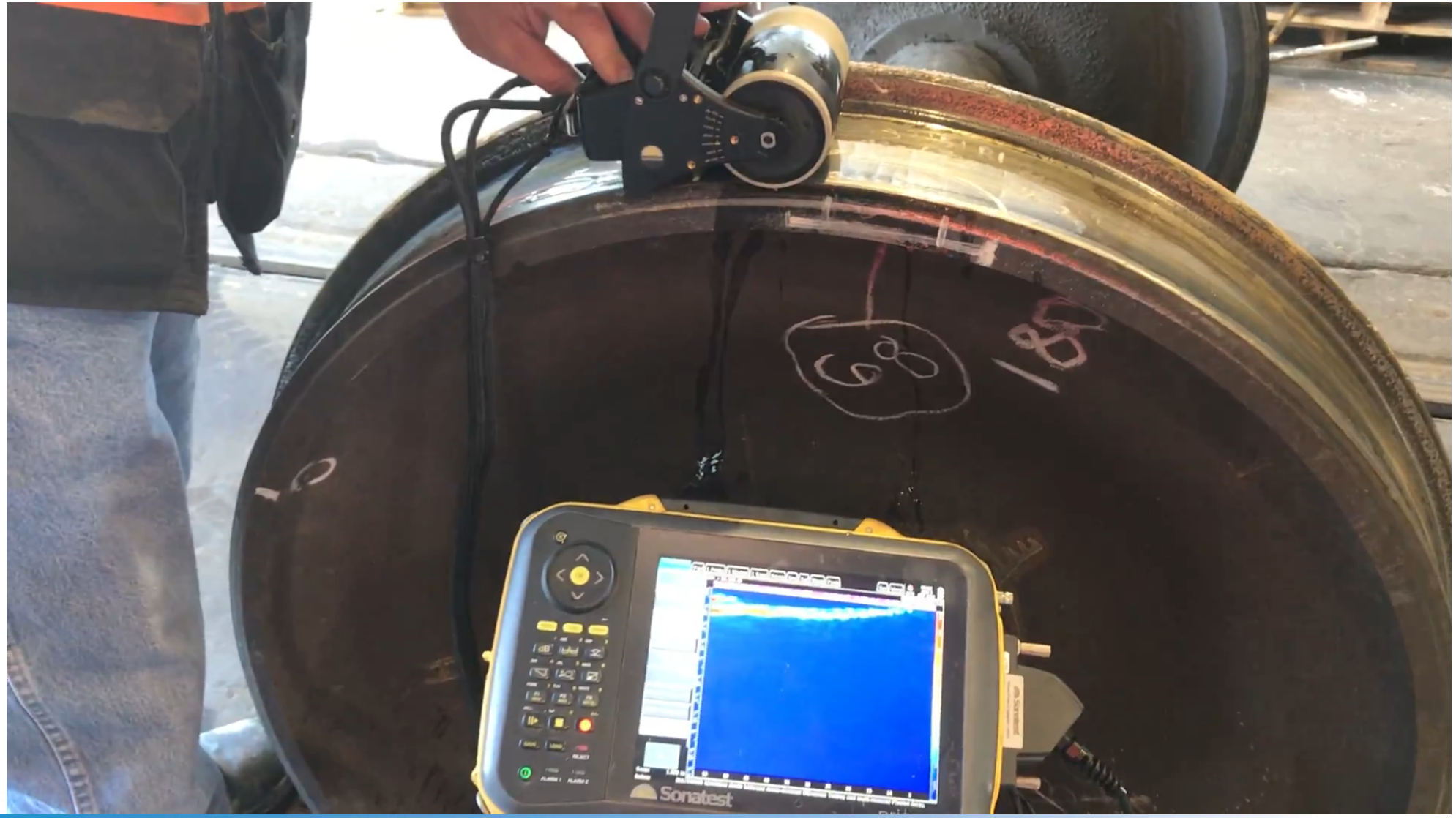




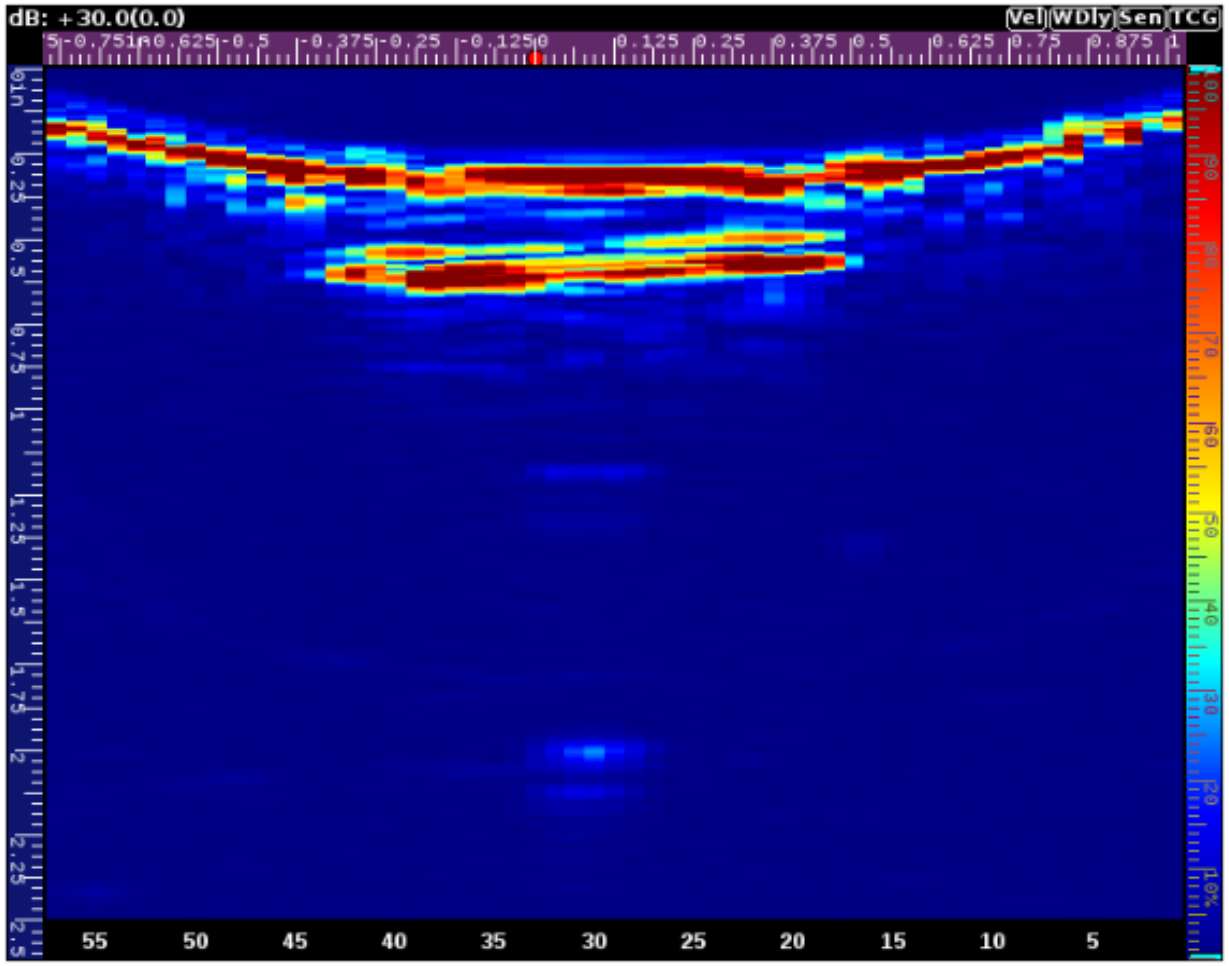
FAST Car 33395 Wheel R3

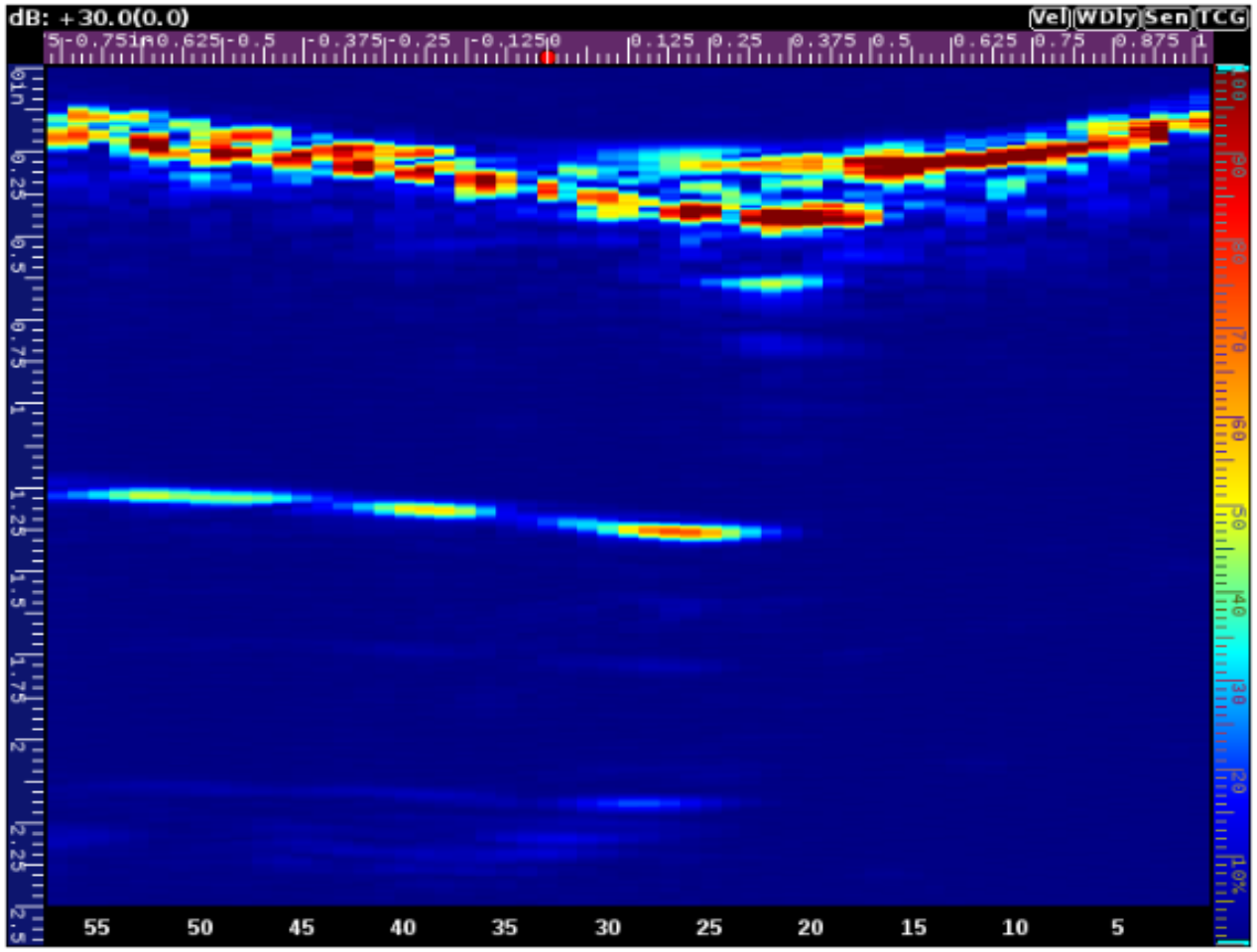
- Detected by 0° inboard/ outboard probes
- Hand-UT Verification
  - 3.25-inch (L) x 2.75-inch (W)

Hand-held Phased Array UT Verification



Hand-held Phased Array UT Verification

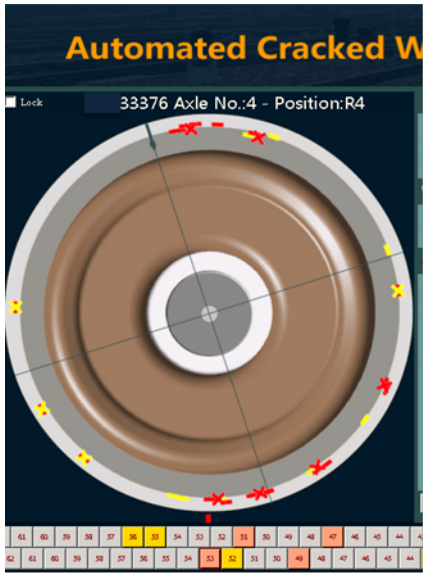




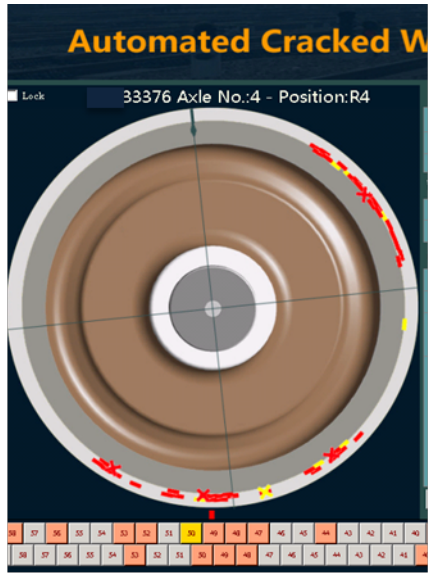
Prior Year Removals
&
UT Verification

FAST Car 33376 Wheel R4

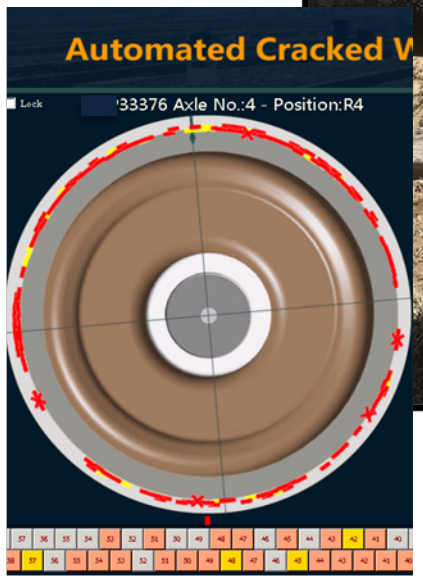
- Total of 94,327 miles and 13.48 MGTM at FAST from 01/2013 to 03/2017
- No visible surface conditions observed in the wheel tread



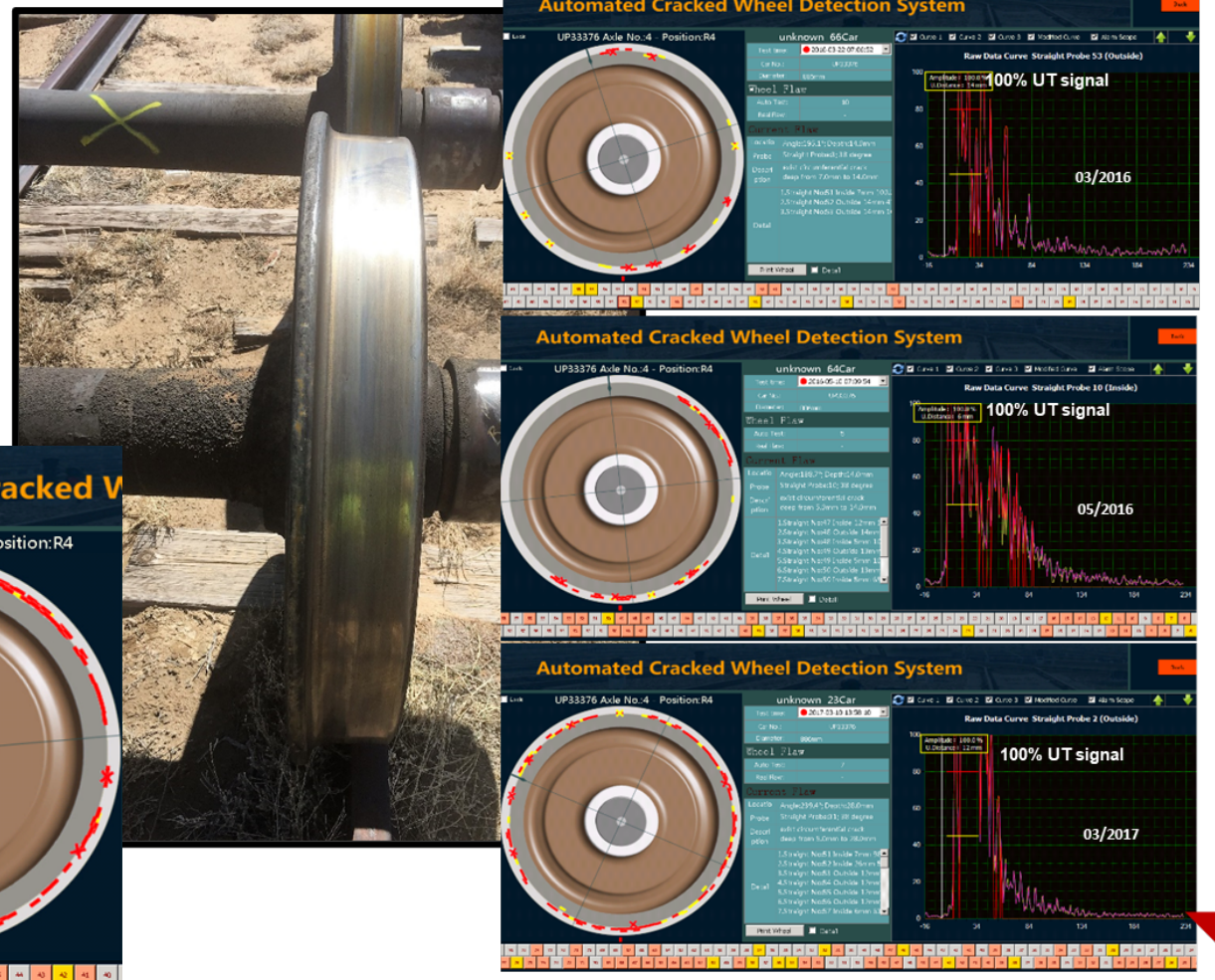
Initial



3 Months

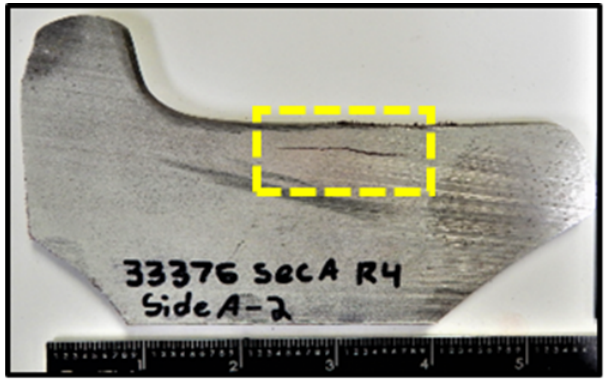


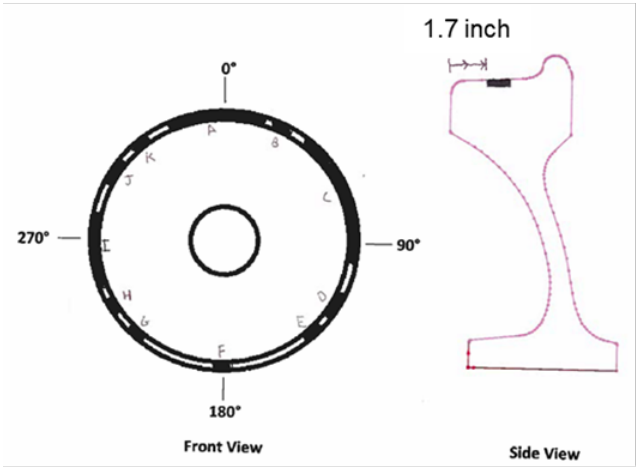
1 year



FAST Car 33376 Wheel R4

- Hand UT NDE findings:
  - Sub-surface fatigue cracks
    - Length: entire circumference
    - Width: 1.4-inch to 1.5-inch
    - Depth: 0.24-inch to 0.36-inch
    - Location:1.7-inch from the rim face





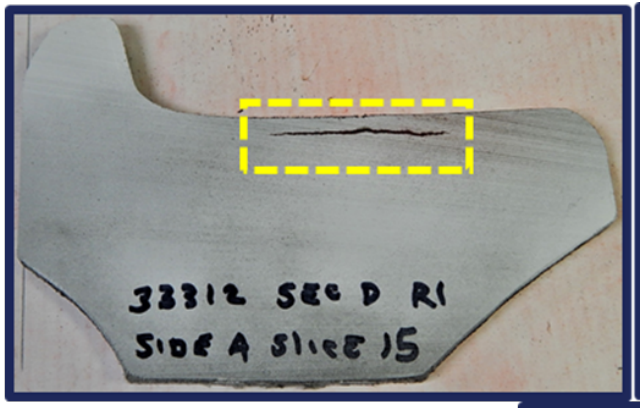
Hand-UT Flaw Mapping

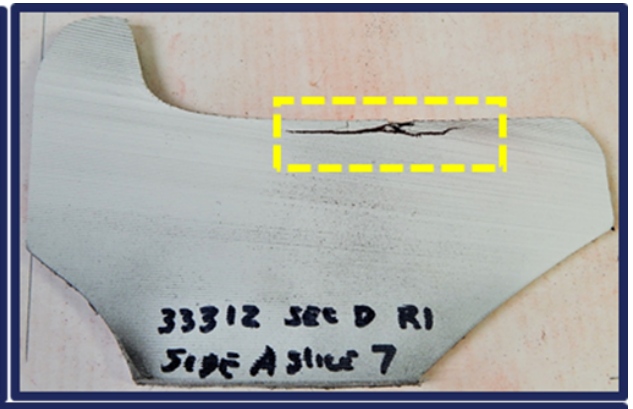
FAST Car 33312 Wheel R1

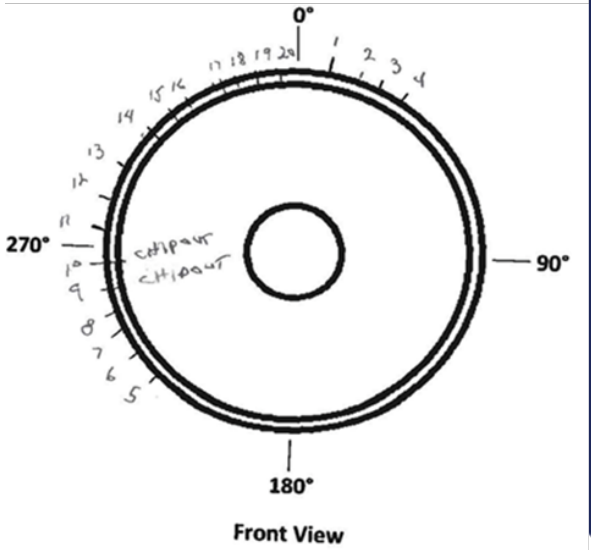
- Class C wheel manufactured in November 2004
- Total of 166,131 miles and 23.76 MGTM at FAST from 09/2009 to 05/2016
- RCF/spalling observed at two locations next to one another in the wheel tread
- Spall length and width was 1.2-inch (30 mm) by 0.8-inch (20 mm), respectively

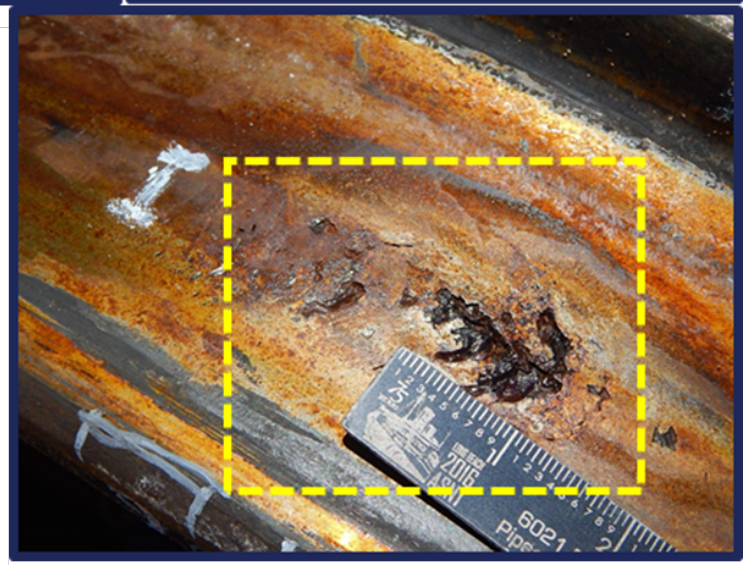
FAST Car 33312 Wheel R1

- Hand-UT NDE findings:
  - Sub-surface fatigue cracks:
    - Length: 0.6-inch to 4.0-inch (15 mm to 102 mm)
    - Width: 0.3-inch to 1.0-inch (8 mm to 25 mm)
    - Depth: 0.19-inch to 0.25-inch (5 mm to 7 mm)
    - Location: 2.0-inch (51 mm) from the rim face (half of the entire circumference)









Conclusions

- Wayside testing of railway wheels for internal anomalies provides a means for identifying subsurface cracks.
- Automated detection and characterization of cracked wheels presents several advantages to the railroads and wheel manufacturers.
- Results from the testing on FAST train cars demonstrated the defect detection and trending studies for wheels with sub-surface fatigue cracking.
- The hand-held UT verifications were in agreement with the ACWDS findings.

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