Advanced Rolling Stock Condition Monitoring Technologies for Freight Rail Transport

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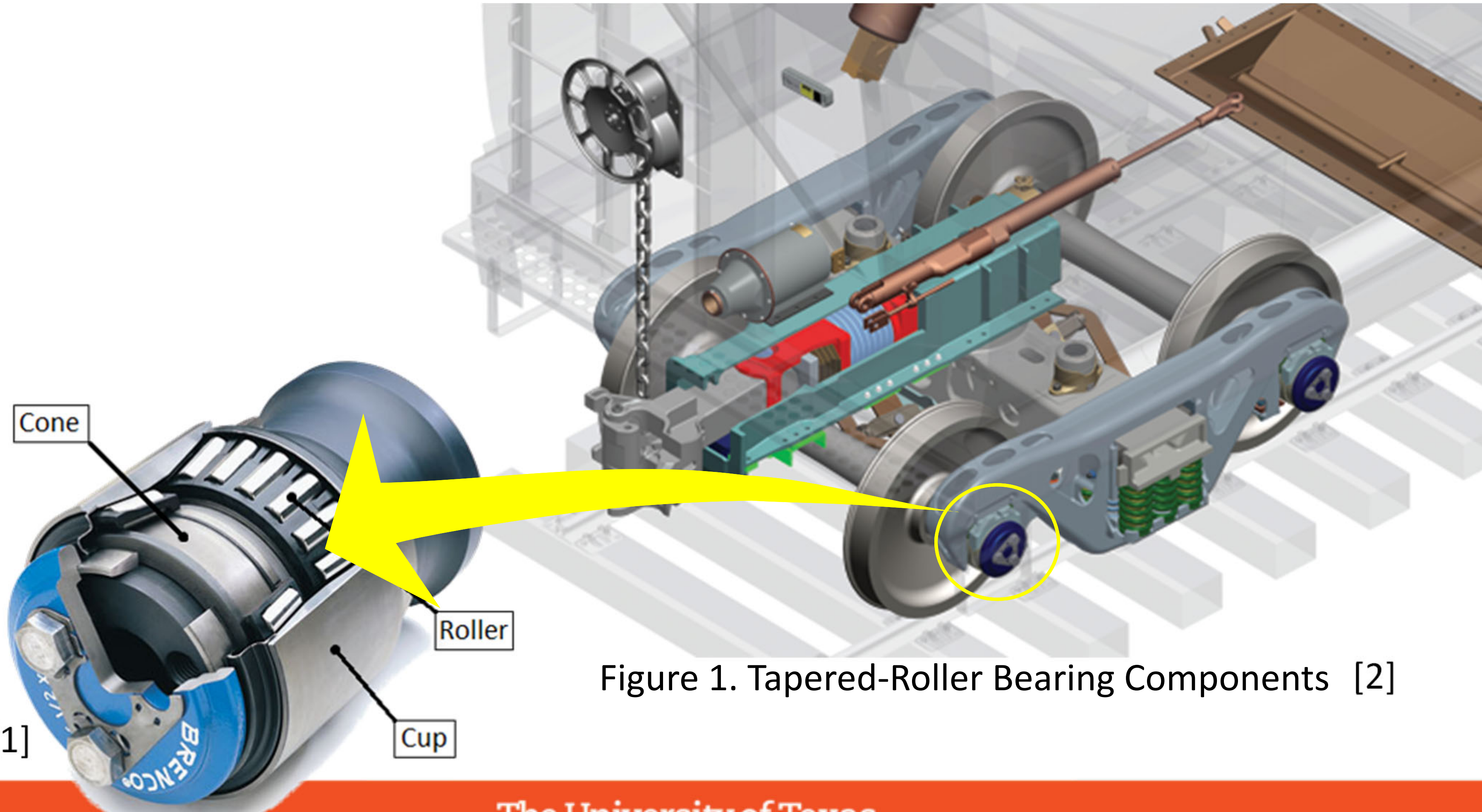
Overview

- Introduction and Background
- Bearing Condition Monitoring Systems
- Accident Case Studies
- UTCRS Proposed Advanced Condition Monitoring System
- Proof of Concept Validation Testing
- Results and Analysis
    - Laboratory Testing
    - 2015 TTCI Field Test
- Other UTCRS Ongoing Research and Capabilities
- UTCRS Research Group

BEARING ASSEMBLY

Bearing Assembly



[1]

Figure 1. Tapered-Roller Bearing Components [2]

BEARING FAILURE MODES

Bearing Failure Modes

Geometric Defects

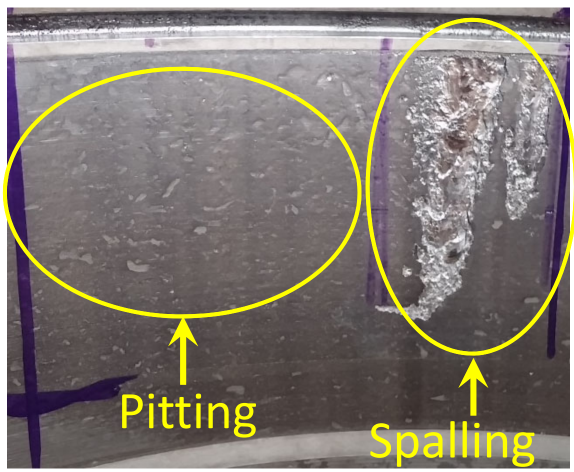
- Geometric inconsistencies of bearing components
- Out-of-tolerance components due to manufacturing errors

Local Defects

- Spalls
- Pits
- Cracks

Distributed Defects

- Waviness of raceways
- Asperities on multiple bearing components
- Water-etch



Water-etch

Figure 2. Example of a localized defect (left) and distributed defect (right)

BEARING CONDITION MONITORING SYSTEMS

Hot-Box Detectors (HBDs)

- Hot-Box Detectors (HBDs) use infrared sensors to measure the temperature radiated from bearings, wheels, axles, and brakes.
- Over 6,000 in use in the U.S. [3].
- 119 train derailments due to overheated bearings from 2010 to 2016 in the U.S. and Canada [4].

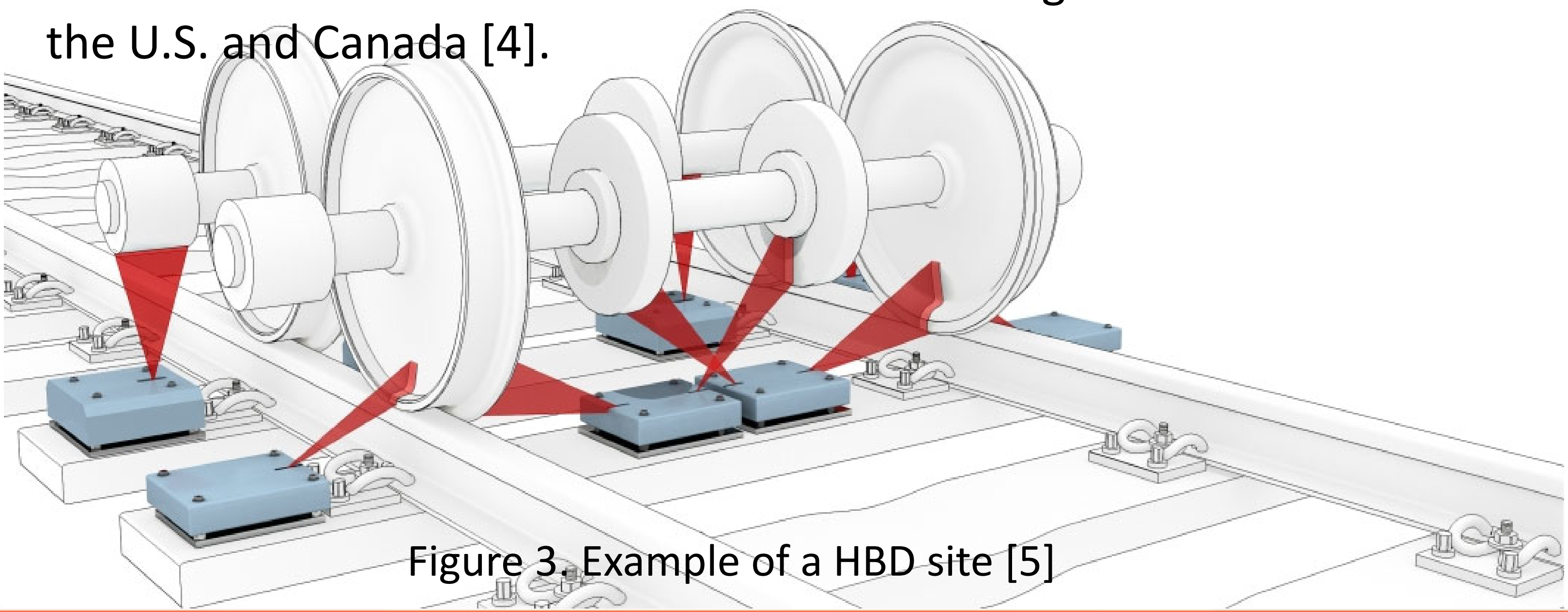


Figure 3. Example of a HBD site [5]

Trackside Acoustic Detector Systems (TADS™)

- Uses microphones to detect high risk defects in components such as “growlers”.
- “Growlers” are severely spalled bearing components containing spalls that occupy more than 90% of bearing component’s contact surface.
- Alerts train operator to stop immediately if a defective bearing is detected.
- 18 systems used in the U.S. and Canada. [7]

Figure 4. TADS™ site and defects detected by TADS™ [6]

ACCIDENT CASE STUDY

Railway Investigation Report R13T0122

- Approximately 10:00 a.m. E.S.T., June 02, 2013.
- Canadian Pacific Railway freight train 119-01, heading north to Sudbury, Ontario, Canada, at 35 mph, had 6 cars derail.
- Some of the cars that derailed struck the bridge, causing for the bridge to collapse, releasing several hazardous materials into the river.
- CP 119-01 did not trigger any of the 6 HBDs between Mactier and Sudbury before derailing shortly before reaching Sudbury.

Figure 5. Travel path of CP 119-01 [8]

Railway Investigation Report R13T0122

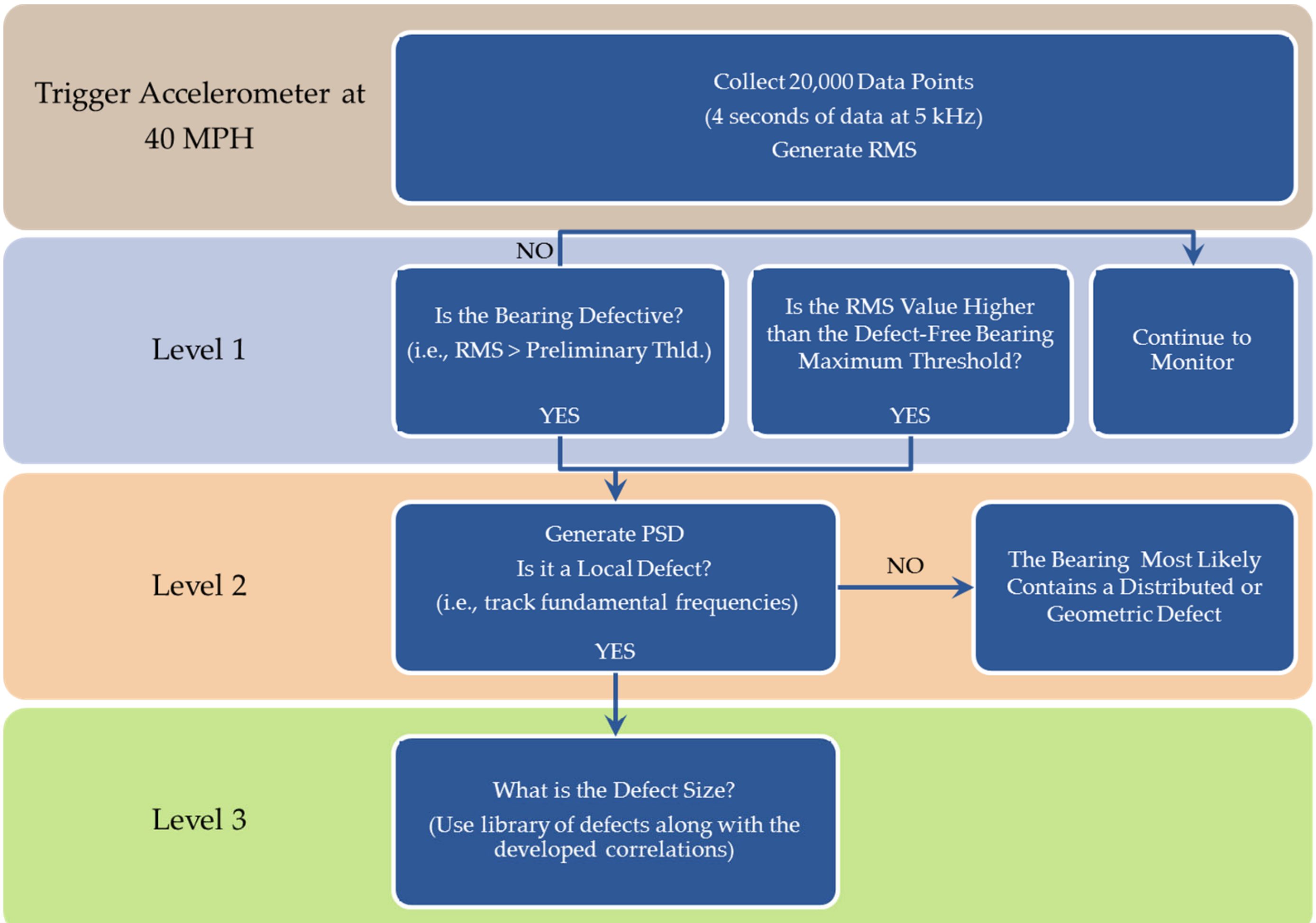
Figure 6. Photograph of CP 119-01 derailment [9]

Railway Investigation Report R13T0122

Figure 7. Photographs of the burnt-off axle journal stub (left), cup (center), and outboard cone assembly (right) [8]

UTCRS PROPOSED ADVANCED CONDITION MONITORING SYSTEM

Proposed Method Using On-board Sensors



Instrumentation Setup

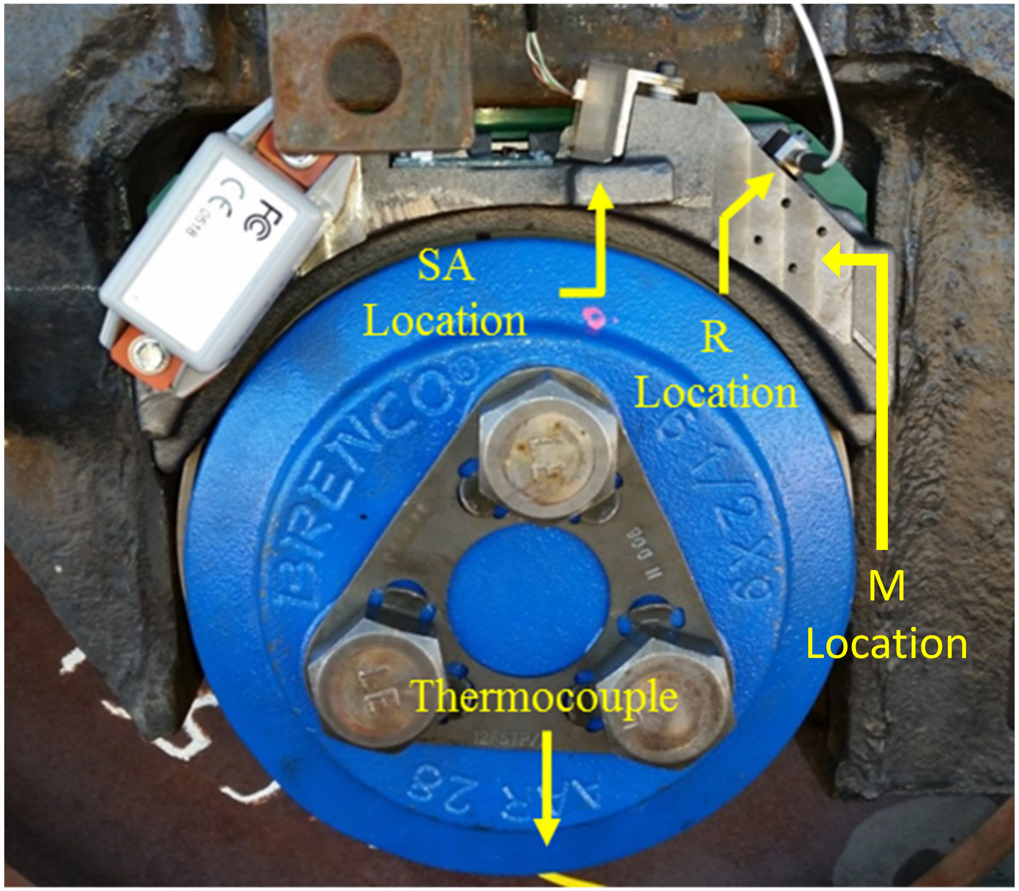


Figure 8. Modified bearing adapter showing sensor locations

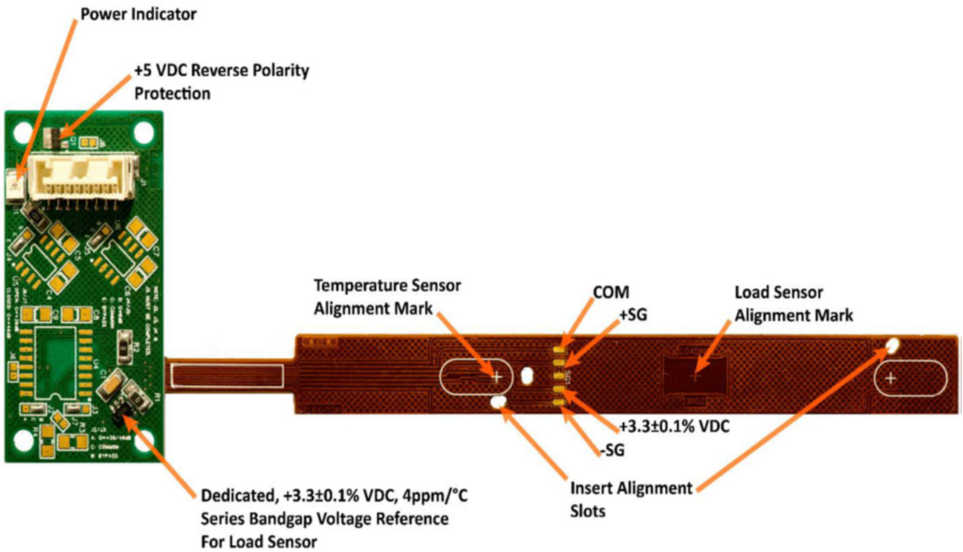


Figure 9. Adapter Sensor Insert Flex Circuit

Figure 10. Load Sensor Insert Assembly

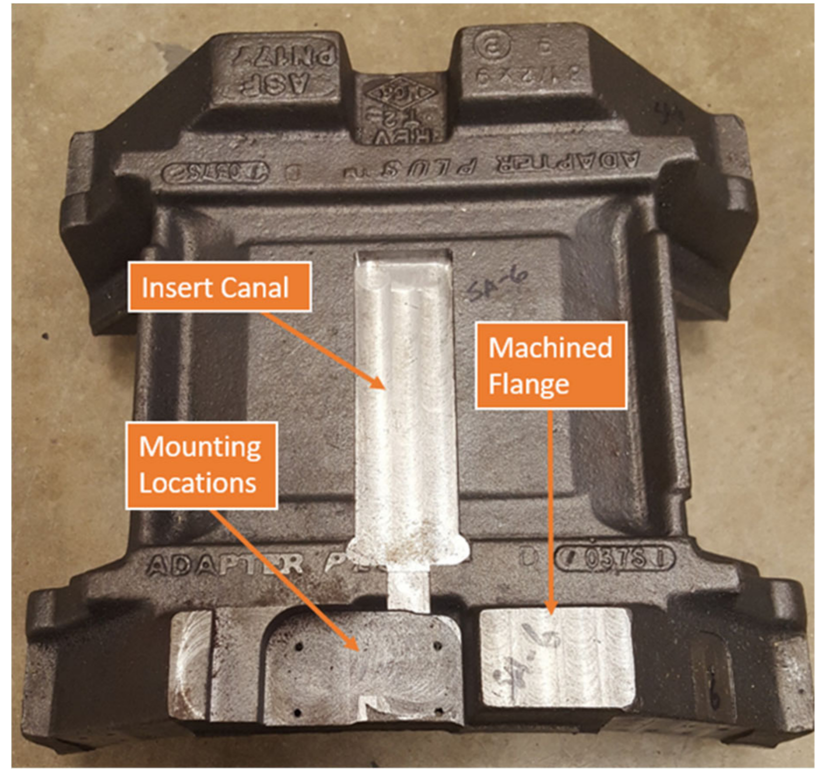


Figure 11. Smart Adapter Machined for Load Insert Capability

Fundamental Frequencies

	Fundamental Frequencies	Defect Frequencies
ω_o = angular speed of axle in Hz	$\omega_{cone} = \omega_o$	$\omega_{out} = 23\omega_{cage}$
R_{cone} = 3.578367 in.	$\omega_{cage} = \left(\frac{R_{cone}}{R_{cone} + R_{cup}}\right)\omega_{cone}$	$\omega_{in} = 23(\omega_{cone} - \omega_{cage})$
R_{cup} = 4.408067in.	$\omega_{roller} = \left(\frac{R_{cone}}{D_{roller}}\right)\omega_{cone}$	$\omega_{rolldef} = \left(\frac{R_{cup}}{R_{roller}}\right)\omega_{cage}$
D_{roller} = 0.8425in.		

Level 2 Analysis: Generate PSD

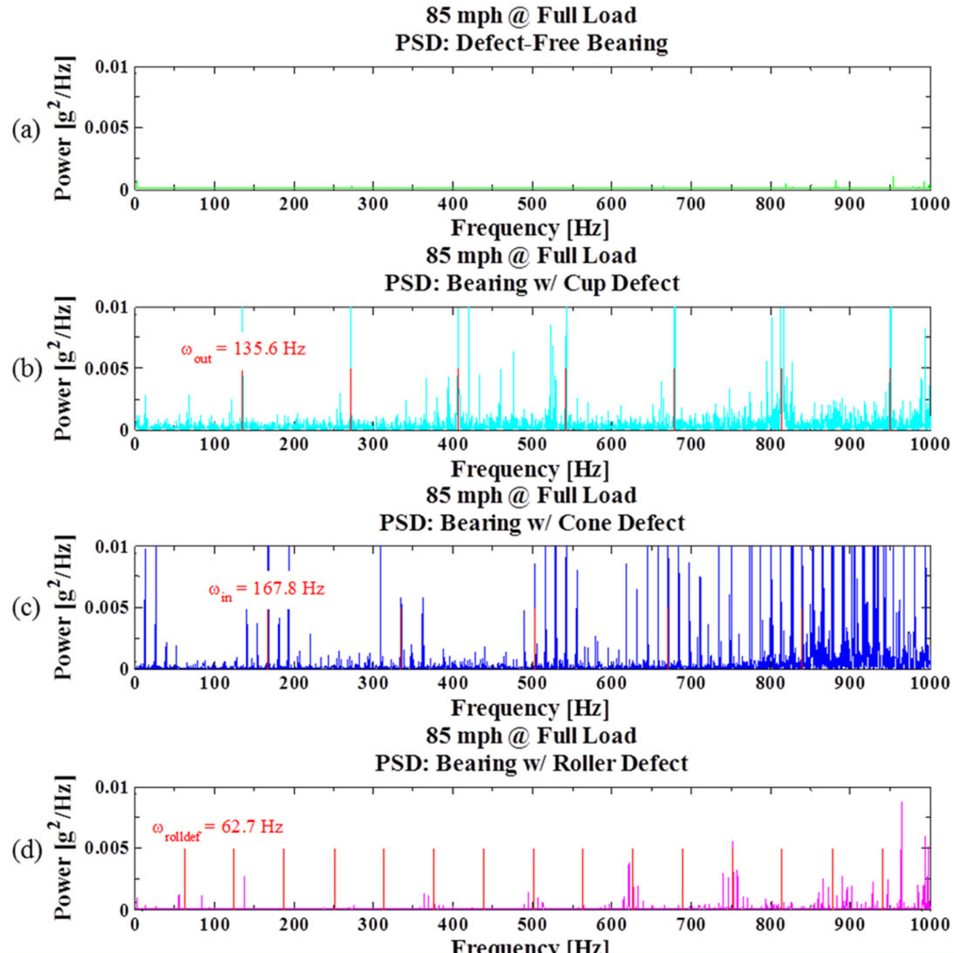


Figure 12. Examples of PSD plots for healthy and defective bearings

PROOF OF CONCEPT VALIDATION TESTING

UTCRS Bearing Test Rigs

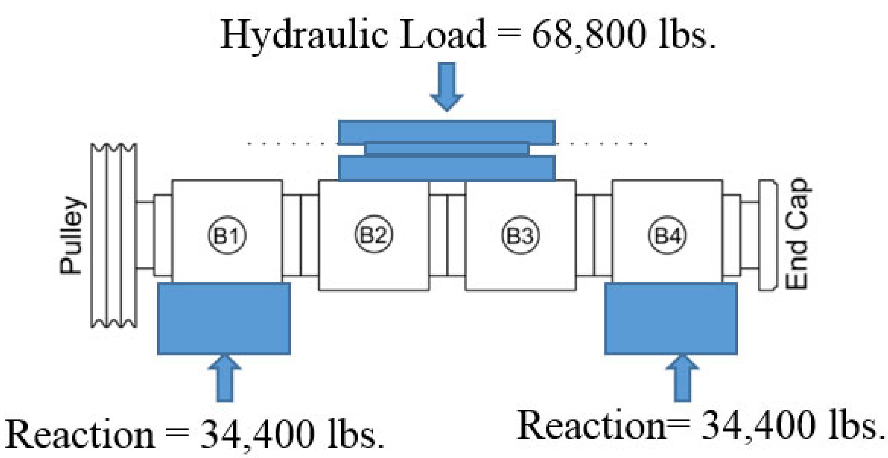


Figure 13. Four Bearing Test Rig (4BT)

UTCRS Bearing Test Rigs

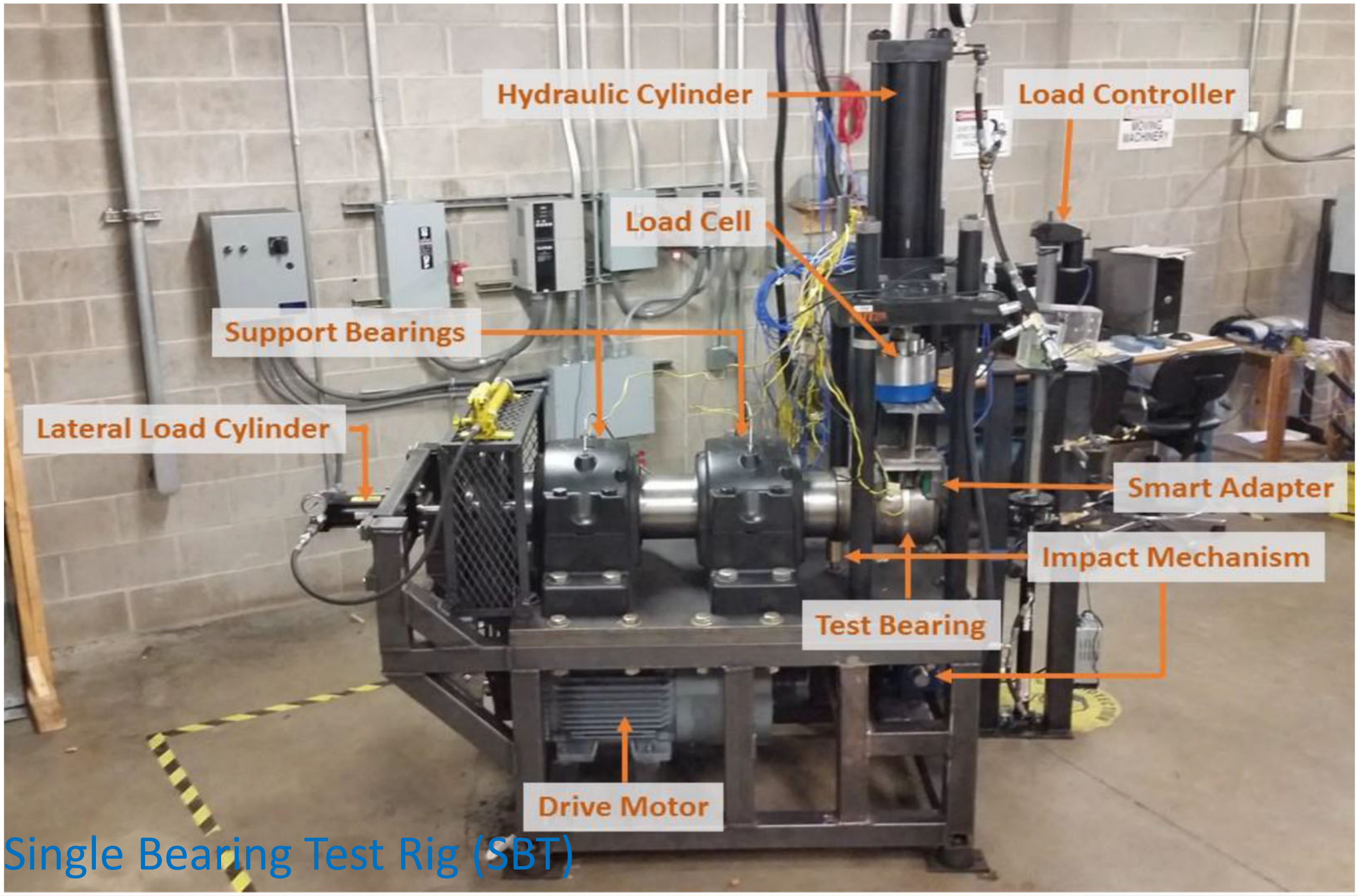


Figure 14. Single Bearing Test Rig (SBT)

Instrumentation Setup

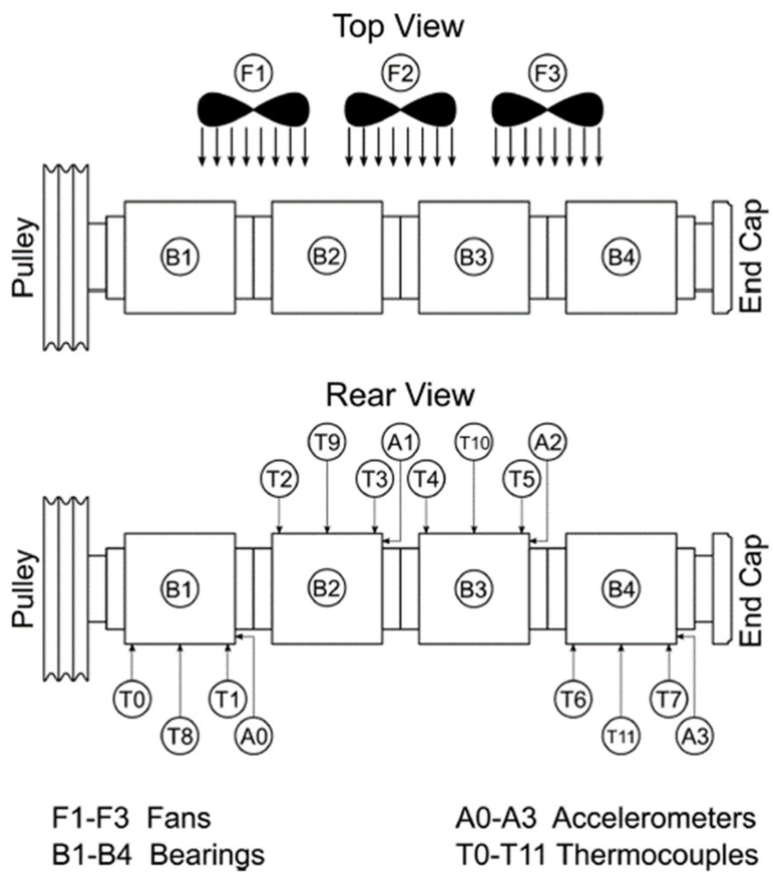


Figure 15. Top and rear views of 4BT including sensor locations

Test Speeds

Table 1. Typical speeds used to perform the experiments in this study

Axle Speed [RPM]	Track Speed [km/h] / [mph]
280	48 / 30
327	56 / 35
373	64 / 40
420	72 / 45
467	80 / 50
498	85 / 53
514	89 / 55
560	97 / 60
618	106 / 66
699	121 / 75
799	137 / 85

Field Test Railcar Setup at TTCI

Figure 16. A picture of the business car and the freight railcar being instrumented for the field test at TTCI

Field Test Railcar Setup at TTCI

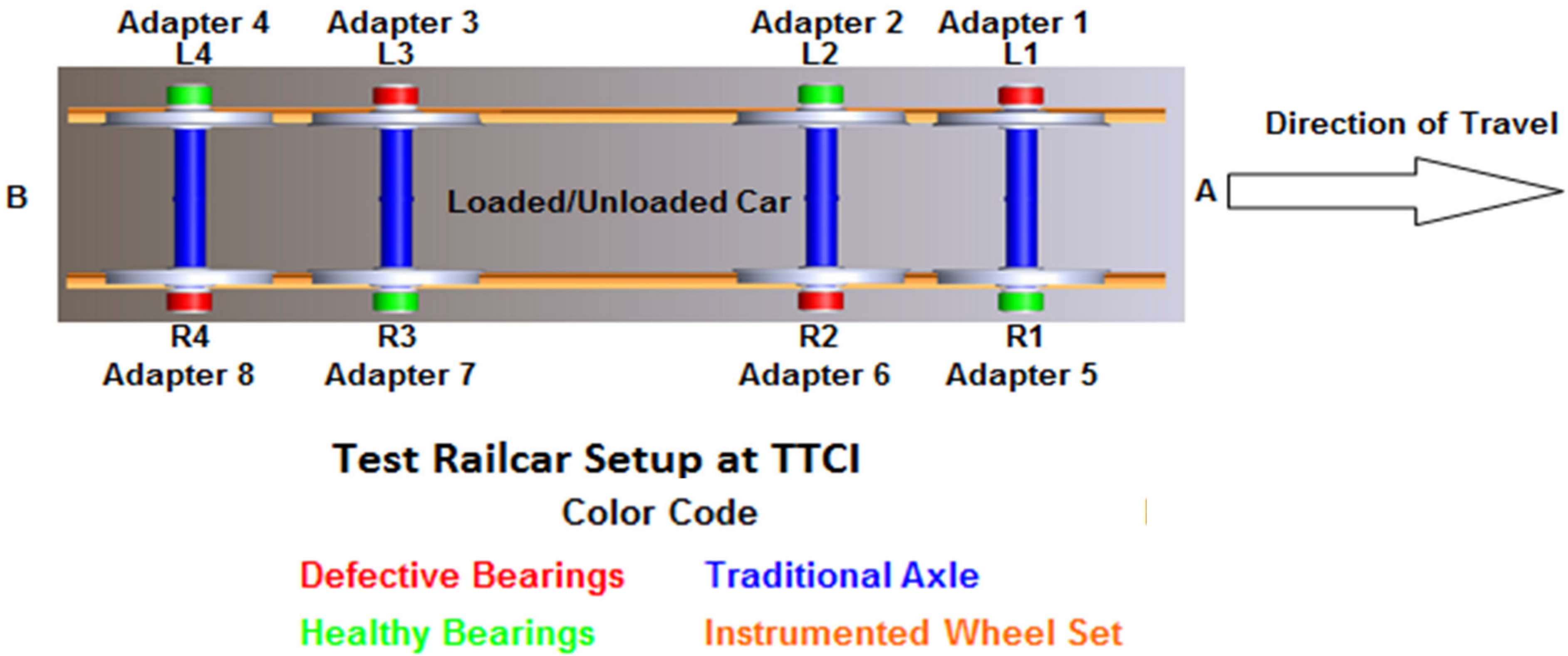


Figure 17. Test Railcar Setup at TTCI

Laboratory Testing

RESULTS AND ANALYSIS

Experiment 201A: Pre-Test Information

Pre-Test
Defect Size:
14.2 cm^2
(2.2 in^2)

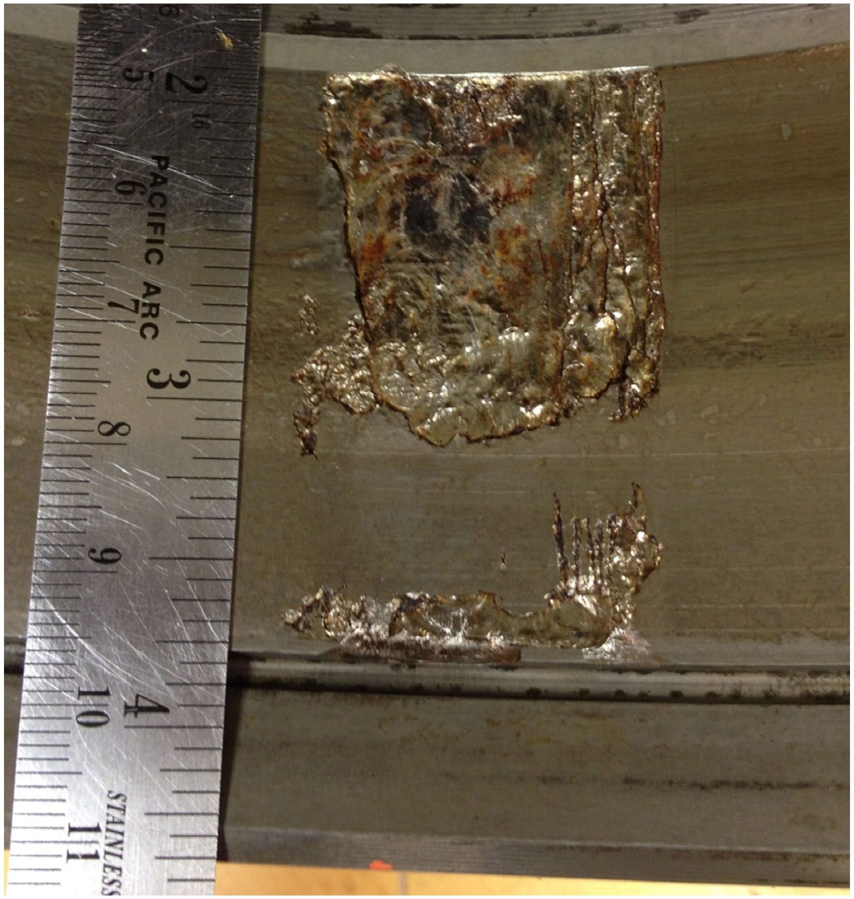


Figure 18. Starting cup spall for Experiment 201A

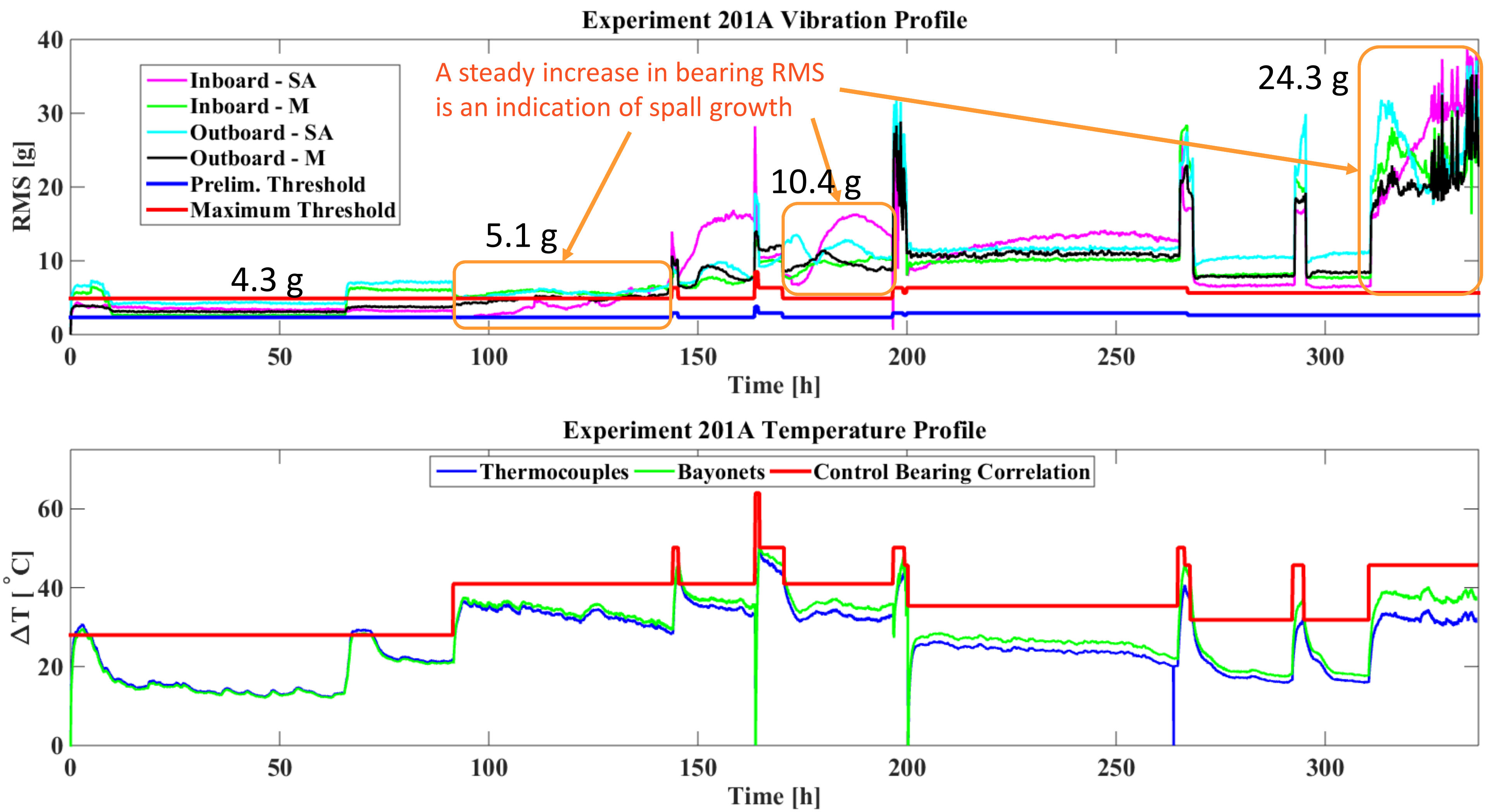


Figure 19. Vibration and temperature profiles for Experiment 201A [13]

Level 1 Analysis RMS Values

Exp. 201A							
Load [%]	17	17	17	17	17	17	100
Speed [MPH]	53	53	53	53	53	53	53
IB-SA	3.8	3.6	3.4	3.3	3.2	3.2	2.6
IB-M	**5.5**	2.6	2.6	4.8	**6.1**	**6.1**	**5.4**
OB-SA	**6.4**	4.2	4.3	**6.0**	**7.1**	**7.1**	**5.2**
OB-M	3.7	3.1	3.1	3.5	3.7	3.7	4.4
Avg. Thld.	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Max. Thld.	4.9	4.9	4.9	4.9	4.9	4.9	4.9

Level 1 Analysis RMS Values

Exp. 201A								
Load [%]	100	100	100	100	100	100	100	100
Speed [MPH]	53	53	66	53	53	85	66	53
IB-SA	3.9	**5.8**	**10.5**	**11.7**	**15.8**	**18.3**	**10.6**	**7.5**
IB-M	**5.8**	**6.0**	**8.5**	**6.9**	**7.3**	**12.4**	**10.1**	**8.3**
OB-SA	**5.7**	**6.0**	**8.7**	**7.6**	**8.9**	**18.6**	**10.0**	**12.3**
OB-M	**4.9**	**5.2**	**9.9**	**7.4**	**8.1**	**13.6**	**11.7**	**9.2**
Avg. Thld.	2.3	2.3	2.9	2.3	2.3	3.8	2.9	2.3
Max. Thld.	4.9	4.9	6.3	4.9	4.9	8.5	6.3	4.9

Level 2 Analysis

IB-SA							
Load [%]	17	17	17	17	17	17	100
Speed [MPH]	53	53	53	53	53	53	53
Max/Sum [%]	**98**	**92**	**94**	**96**	**92**	**92**	**97**
Highest Magnitude	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**

IB-M							
Load [%]	17	17	17	17	17	17	100
Speed [MPH]	53	53	53	53	53	53	53
Max/Sum [%]	**85**	**92**	**94**	**82**	**61**	**61**	**93**
Highest Magnitude	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**

Level 2 Analysis

IB-SA								
Load [%]	100	100	100	100	100	100	100	100
Speed [MPH]	53	53	66	53	53	85	66	53
Max/Sum [%]	**99**	**99**	**99**	**99**	**97**	**100**	**96**	**97**
Highest Magnitude	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**

IB-M								
Load [%]	100	100	100	100	100	100	100	100
Speed [MPH]	53	53	66	53	53	85	66	53
Max/Sum [%]	**92**	**90**	**98**	**88**	**91**	**98**	**97**	**94**
Highest Magnitude	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**	**Cup**

Experiment 201A: Post-Test Information

Post-Test Defect Size: 20.9 cm^2 (3.24 in^2)

Figure 20. Ending cup spall for Experiment 201A

Distance traveled: 32,955 km (20,477 miles)

2015 TTCI Field Test

RESULTS AND ANALYSIS

Laboratory Data vs. Field Data

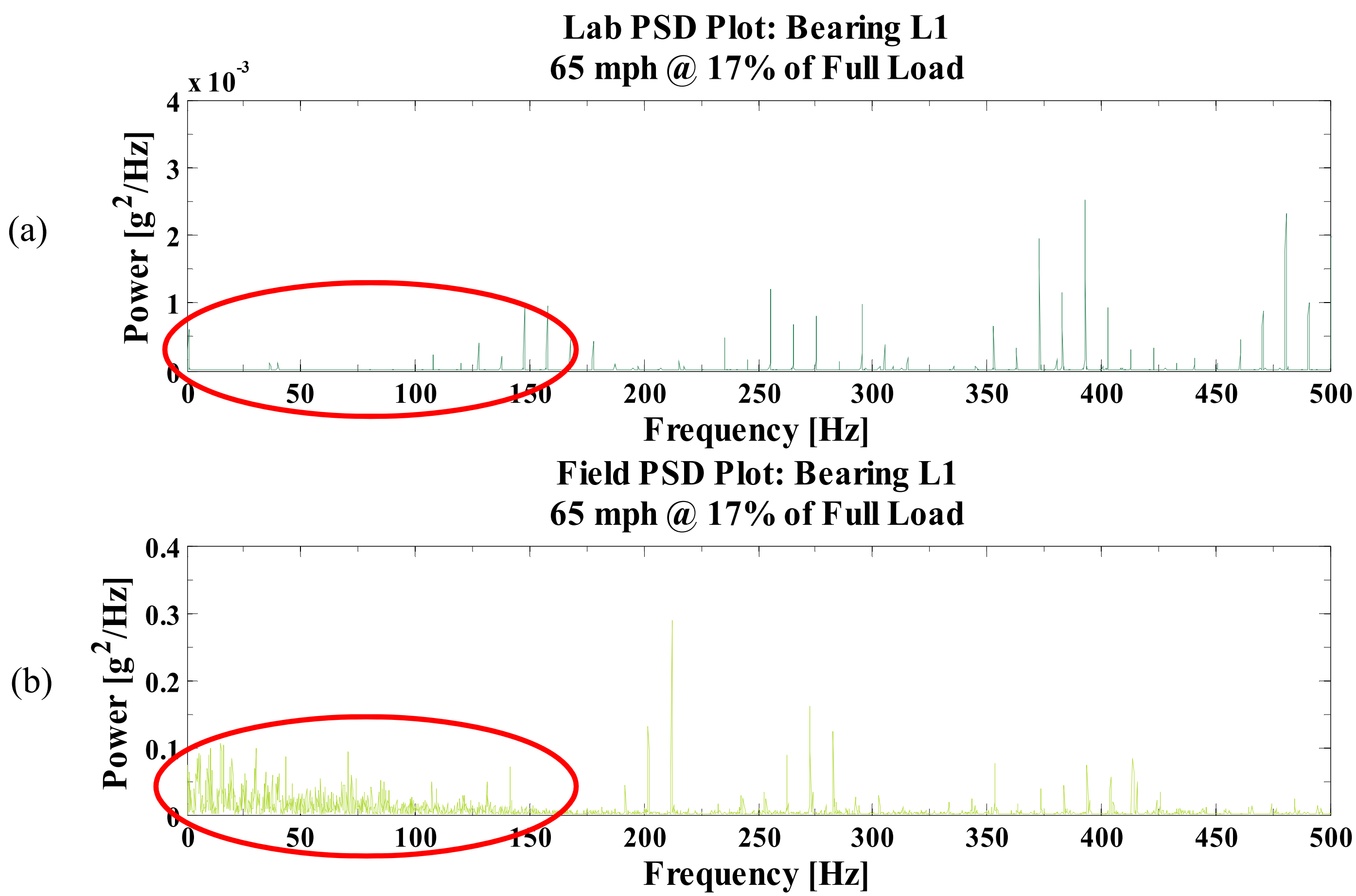


Figure 21. Difference between laboratory data and field data

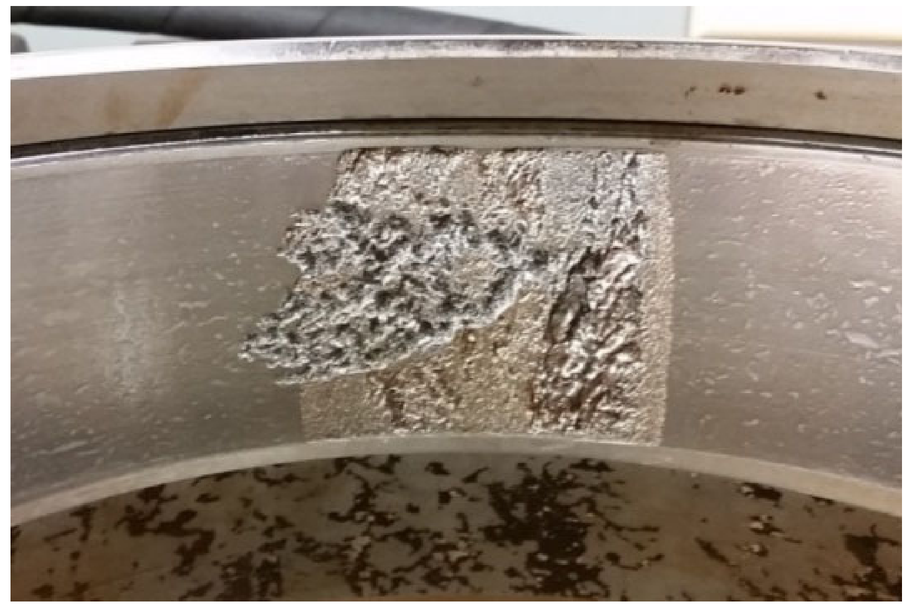
Field Test Data Collected

Total Number of Sample Windows (SW) used for analysis for each speed and load

Day 1 & 2 (100% of Full-Load)			Day 3 (17% of Full-Load)		
Speed [mph]	End A	End B	**Speed [mph]**	End A	End B
30	109	67	**30**	48	40
40	58	98	**40**	81	57
50	111	102	**50**	58	53
55	97	93	**55**	29	30
57	-	29	**60**	20	24
60	-	27	**65**	18	25

2015 Field Test: Pre-Test Information

L1 Cone Defect
Max Area: 2.2 in^2
Represents 2.5% of Combined Cone Raceway Area



R2 Cup Defect
Max Area: 5.3 in^2
Represents 4.7% of Combined Cup Raceway Area

Level 1: Defect Detection

Percentages of SWs with RMS values greater than the Maximum Threshold at End A

End A	17% Load		100% Load	
Speed [mph]	L1 (Cone Defect)	R2 (Cup Defect)	L1 (Cone Defect)	R2 (Cup Defect)
40	97%	100%	100%	83%
50	100%	100%	100%	100%
55	100%	100%	100%	100%
57	100%	100%	-	-
60	100%	100%	-	-

Level 2: Defect Type

Percentages of SWs having the corresponding defective component's normalized defect energy (NDE) greater than 50% at End A

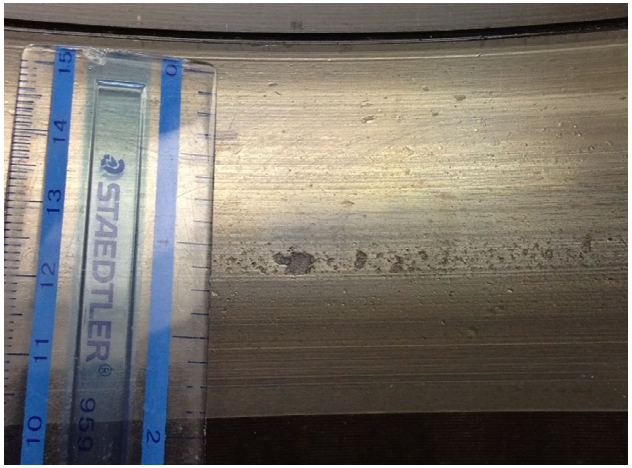
End A	17% Load		100% Load	
Speed [mph]	L1 (Cone Defect)	R2 (Cup Defect)	L1 (Cone Defect)	R2 (Cup Defect)
40	3%	47%	31%	100%
50	43%	80%	78%	99%
55	72%	100%	67%	98%
57	100%	100%	-	-
60	100%	92%	-	-

Smallest Spall Size Detected

U.S. Penny

Diameter: 0.75"

Area = 0.442 in^2



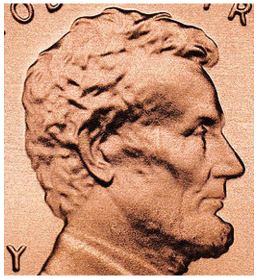
Smallest Spall Detected

L_{max} = 0.144"

W_{max} = 0.791"

Area = 0.114 in^2

% of cup raceway = 0.1%



President Lincoln’s Head on a Penny

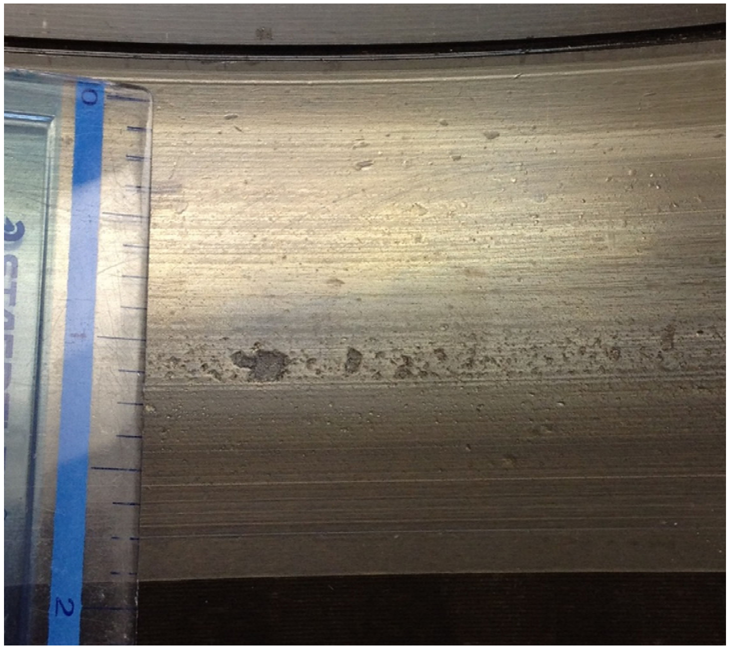
L_{max} = 0.2"

W_{max} = 0.5"

Area = 0.1 in^2

Conclusions

- Current wayside condition monitoring systems are reactive and inefficient.
- Temperature measurements alone are not a reliable or effective metric for quantifying bearing health.
- Onboard condition monitoring techniques utilizing vibration and temperature sensors provide a more reliable and proactive approach to tracking the health of railroad bearings in service.
- Accurately identifying bearing defects at an early stage, and tracking these defects as they develop and worsen can assist railroads in scheduling appropriate maintenance cycles, and avoid costly and unnecessary train stoppages and delays, not to mention preventing severe damages to the rail infrastructure that can result if defects progress undetected leading to catastrophic derailments.



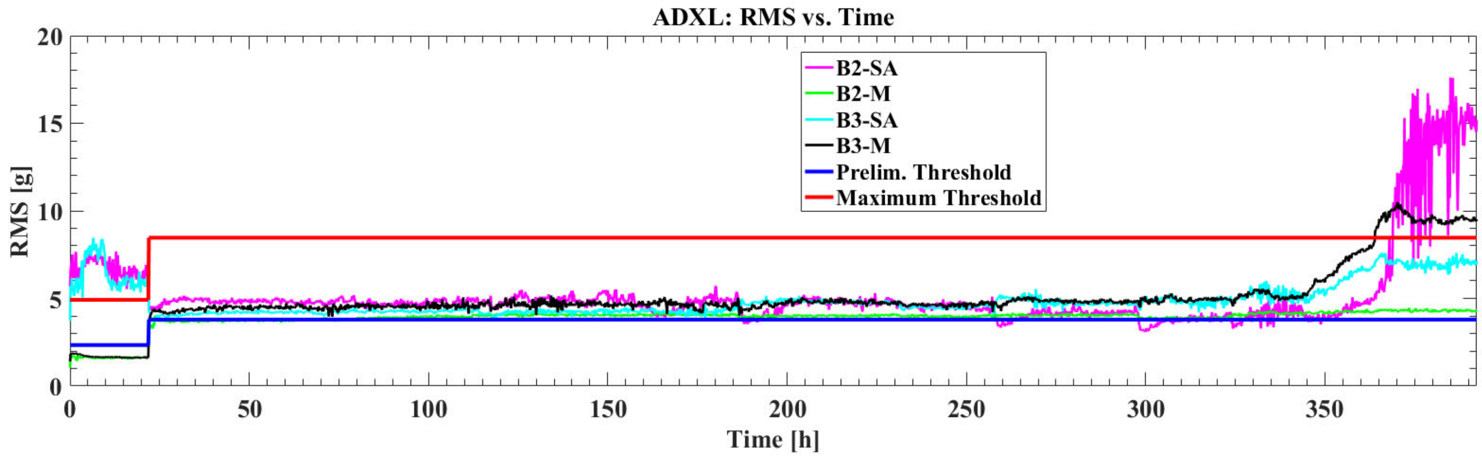
123,744 miles

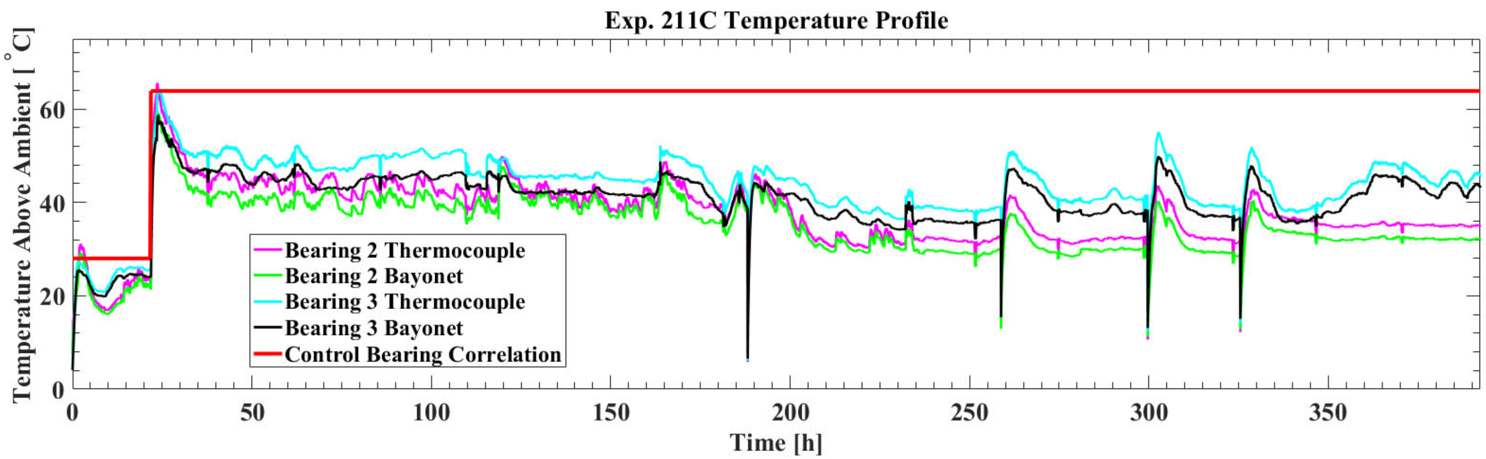
22 round trips from N.Y.C. to L.A.

Size [in^2]:	0.114	Size [in^2]:	3.24
RMS [g]:	8.0	RMS [g]:	18.3
Absolute Temperature [°C]:	74	Absolute Temperature [°C]:	78
Temp. Above Ambient [°C]:	55	Temp. Above Ambient [°C]:	53
Control Temp. [°C]:	85	Control Temp. [°C]:	85

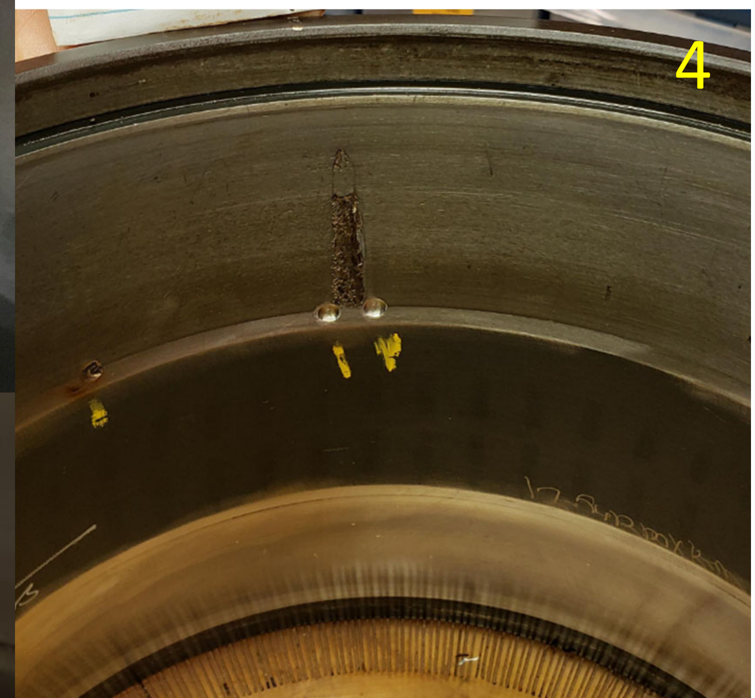
OTHER UTCRS ONGOING RESEARCH AND CAPABILITIES

Assessing Performance of Reconditioned Bearings



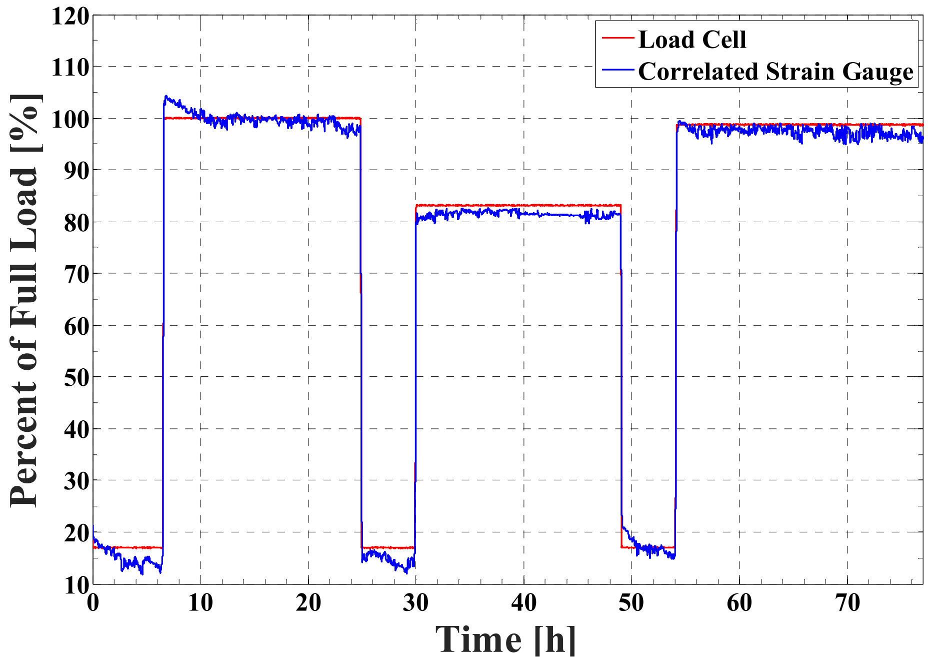


Assessing Performance of Reconditioned Bearings

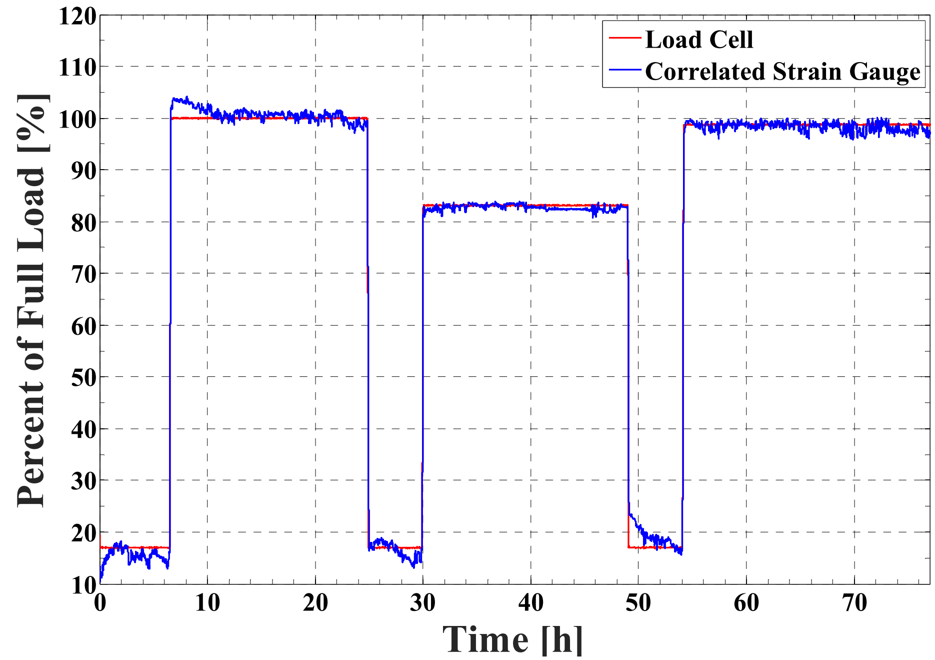


94,000 miles of service operation after bearing was reconditioned

UTCRS Freight Railcar Load Sensor



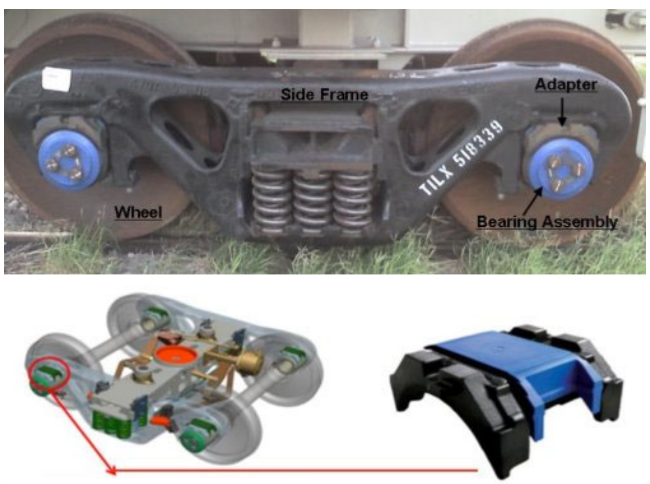
Dynamic test utilizing the second order correlation

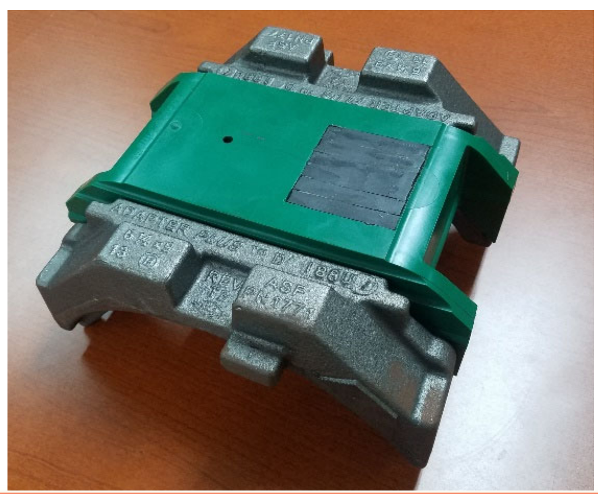


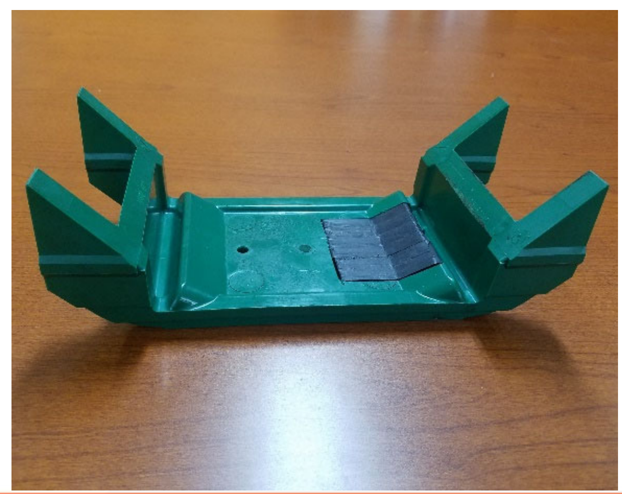
Dynamic test utilizing the multivariate correlation

Conductive Adapter Steering Pad

- The polymer adapter steering pad is used to reduce stress of axle and wear of surrounding components experienced by railcar during daily operation
- Cyclic loading and wear of pad causes copper studs inserted in pad to lose contact and render it non-conductive
- UTCRS created a conductive nanocomposite made of Carbon Nano Fibers (CNFs) and Thermoplastic Polyurethane (TPU) to replace current material

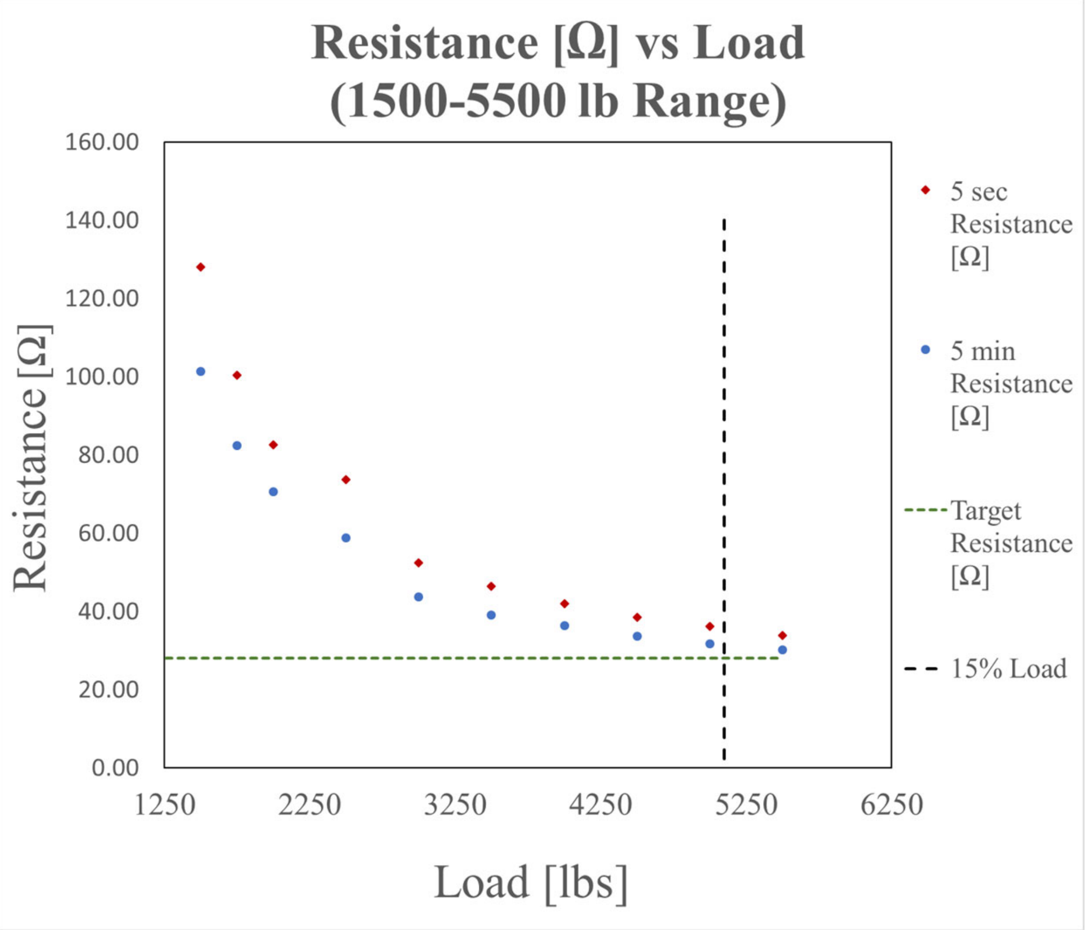






Current Results

- Worked with BASF to develop a nanocomposite with microstructural properties suited for injection molding conductive inserts
- Currently studying the electrical, thermal, mechanical, and fatigue properties of the injection molded parts



UTCRS RESEARCH GROUP

UTCRS Research Group

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- Expertise: Experimental Heat Transfer and Fluid Mechanics; Thermal and Dynamic Analysis of Railroad Rolling Stock; Advanced Bearing Condition Monitoring Systems; and Acoustics and Vibrations.
- 14 Years of Experience Conducting Railroad Research.

Ongoing Research Projects

- Assessing the Efficacy of Railroad Bearing Reconditioning through Service Life Performance Testing. Transportation Technology Center, Inc. (TTCI)
- Low Power Wireless Sensors for Railroad Bearing Health Monitoring. [USDOT]
- Prototyping and Testing of Electrically Conductive Thermoplastic Polyurethane (TPU) Railroad Suspension Pad. [USDOT]
- Development of Predictive Models for Spall Growth in Railroad Bearing Rolling Elements. [USDOT]
- Radiative Heat Transfer Analysis of Railroad Bearings Using a Single Bearing Test Rig for Wayside Thermal Detector Optimization. [USDOT]
- Demonstration of Magnetostrictive Materials for Self-Powered Monitoring of Rail Vehicle Suspension Components. [USDOT]

UTCRS Research Group

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- Expertise: Mechanical behavior of materials and components; Polymer and Composite Processing, Structure, and Performance; Fracture and Failure of Materials and Components; Dental Materials and Structures
- 13 Years of Experience Conducting Railroad Related Research.

Ongoing Research Projects

- Prototyping and Testing of Electrically Conductive Thermoplastic Polyurethane (TPU) Railroad Suspension Pad. [USDOT]
- Development of Predictive Models for Spall Growth in Railroad Bearing Rolling Elements. [USDOT]
- Evaluation of Lubricant Life by Differential Scanning Calorimetry. [USDOT]
- Characterization and Testing of Composite Manhole Covers for Commercial Service. [Private Industry]

Materials Laboratory Resources

- Mechanical Testing (22 kip dynamic, 70k, & 400k Universal Test Machines, Enviro Chamber -40° to 200°C)
- Impact (Charpy, Izod, Instrumented Impact)
- Hardness (Brinell, Rockwell, Shore, Vickers)
- Thermal Analysis (DSC, DMA, TMA, TGA)
- Specialized (Salt Fog, Taber Abraser, RR Moor Fatigue, Sheet Metal Fatigue, Polymer Creep)
- Microscopy (Digital, SEM, AFM)

UTCRS Research Group

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- Expertise: Experimentally Validated Stress, Vibration, and Heat Transfer Finite Element Analysis; Condition-Based Monitoring Systems.
- 10 Years of Experience Conducting Railroad Research.

Relevant Research Projects

- Railroad Bearing Thermal Management including Hysteresis Heating of Railroad Bearing Thermoplastic Elastomer Suspension Pad. [USDOT]
- Development of Predictive Models for Spall Growth in Railroad Bearing Rolling Elements. [USDOT]
- Vibration-Based Defect Detection for Freight Railcar Tapered-Roller Bearings in Field and Laboratory Testing. [USDOT]
- Structural Integrity and Fatigue Life Estimation of Railroad Bearing Adapters for Onboard Monitoring Applications. [USDOT]
- Identifying and Understanding Temperature Trending in Railroad Tapered-Roller Bearings. [USDOT]

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- Expertise: Microwaves; RF Circuits; Electromagnetics; Wireless Sensor Devices; Low Power Electronics.
- 25 Years Experience in Antennas, Wireless, and Sensor Electronics, including 8 Years Experience with Railway Safety Group.

Relevant Research Projects

- Low-power wireless sensors for railway suspension monitoring [Ongoing, USDOT through UTCRS]
- Energy harvesting using magnetostrictove materials. [USDOT through UTCRS]
- Reconfigurable antennas for vehicular communications. [DARPA, ITT]

UTCRS Research Group

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- Expertise: Applied Statistics; Design of Experiments; Reliability; Time Series Analysis; Operations Research; Information Technology; Data Science/Analytics
- 25 Years Experience in Applied Statistics and Data Science, including 6 years with Railway Safety Group.

Relevant Research Projects

- Models for the Residual Life of Railroad Bearing Grease in Laboratory and Industry Applications. [USDOT through UTCRS]
- Modelling and Optimization of the Molten Salt Cleaning Process.
- Study of Processing Variables on the Electrical Resistivity of Conductive Adhesives.

UTCRS Research Group

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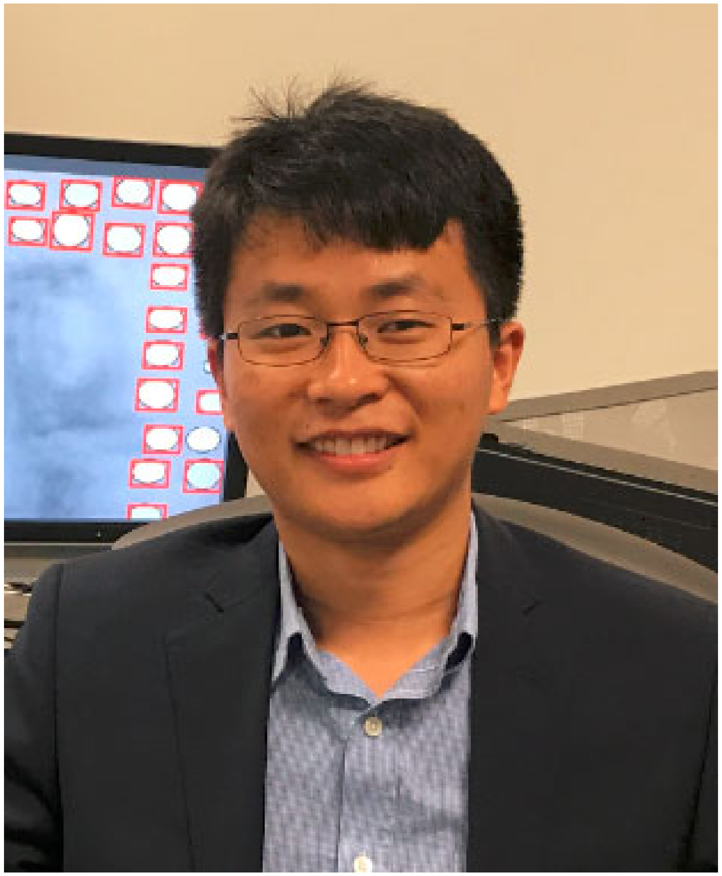
- Expertise: Computer Vision; Artificial Intelligence; Intelligent Transportation Systems; Autonomous Driving.
- 8 Years of Experience Conducting Cross-Domain Research in Computer Vision, Artificial Intelligence and Transportation.



Relevant Research Projects

- Traffic Data Collection for Multiple Vehicle Types from Drone Videos. [On going]
- Integrated Feature Detection and Tracking from Microscope Images of Composite Materials. [Air Force Research Lab]
- Algorithm Development for Reconstruction of Design Elements. [NSF]
- Robust Feature Tracking through Serial Section Microstructural Image Data. [Air Force Research Lab]

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Questions?