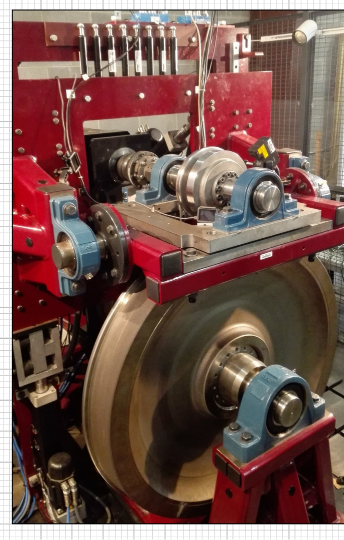
VIRGINIA TECH

Long- and Short-term effect of Top of Rail Friction Modifiers (TORFM) on Traction

Mehdi Ahmadian
J. Bernard Jones Chair and Director

Ahmad Radmehr
Research Scientist

Yu Pan
Research Scientist



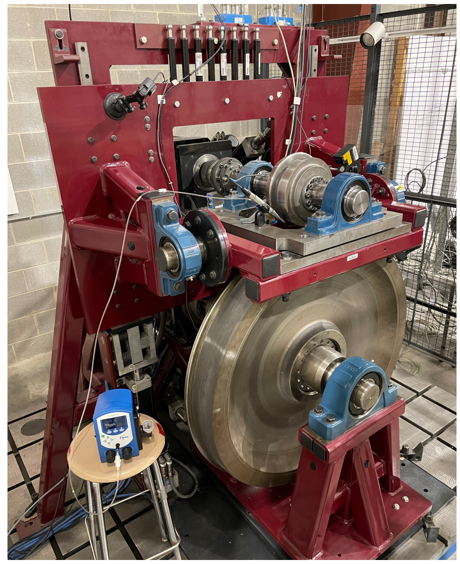
Jan 26, 2022

Acknowledgement

- Financial support of Federal Railroad Administration is greatly acknowledged
- Technical discussions and recommendation by many have been instrumental in achieving the results
  - Federal Railroad Administration
    - Ali Tajaddini
    - Brian Marquis
    - Alexandra Baginski
  - Vtech CMCC
    - Dr. Edwin A. H. Vollebregt

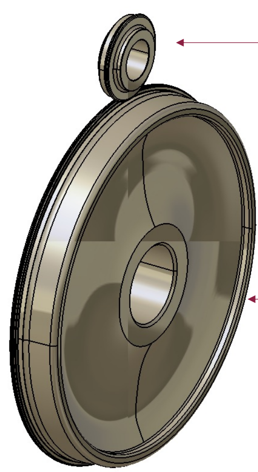
VT-FRA Roller Rig: designed and developed (in house) for precise measurement of contact dynamics in a controlled environment

- The roller rig has six degrees-of-freedom and includes:
  - Two rotating bodies
    - Representing wheel and rail
  - Six linear actuators, controlling
    - Wheel Load
    - Angle of Attack (AoA)
    - Lateral Displacement
    - Cant Angle
  - Two AC motors, rotating
    - Wheel and Roller independently
  - Two load platforms, including
    - eight loadcells
  - Precise surface measurement device
    - Measuring surface changes and wear
  - High-precision fluid dispensing system
    - Dispensing the right amount of contaminants
  - Sound measurement system
    - Recording contact noise
  - Three GoPro cameras



VT-FRA Roller Rig Rotating Bodies Design Overview

The roller is approximately five times bigger than the wheel in diameter to minimize the contact patch distortion



Wheel

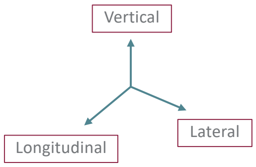
Wheel Profiles
Cylindrical
1/4th scaled AAR-1B

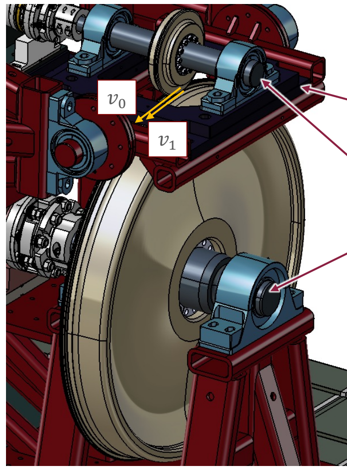
The wheel can be replaced to test with various profiles

Roller

Roller Profile
1/4th scaled US-136 rail

The wheel and roller are driven independently to within 0.1 RPM accuracy, hence allowing precise control of creepage withing a large traction and braking range





The rig includes two load platforms wit four tri-axial PZT loadcells for measuring contact forces and moments

Wheel Load Platform

Two Independent Drivelines

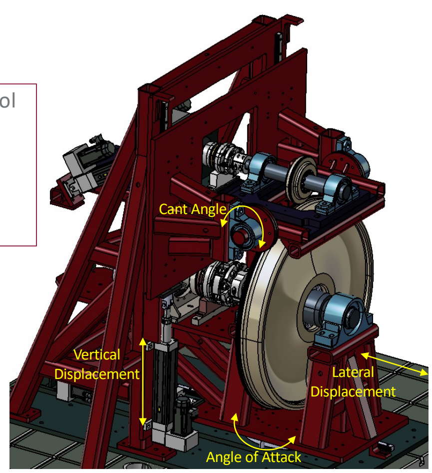
Control the Relative Velocity between the Wheel and the Roller

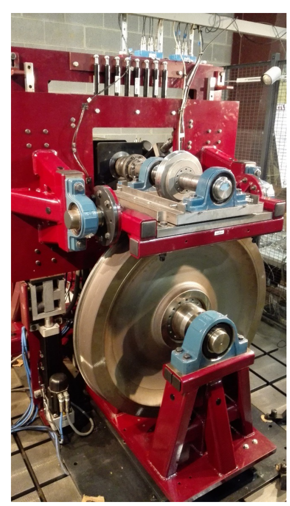
Control Creepage

$$Creepage = \frac{v_0 - v_1}{\frac{1}{2}(v_0 + v_1)}$$

The rig includes six linear actuators to control wheel load, lateral displacement, angle of attack, and cant angle

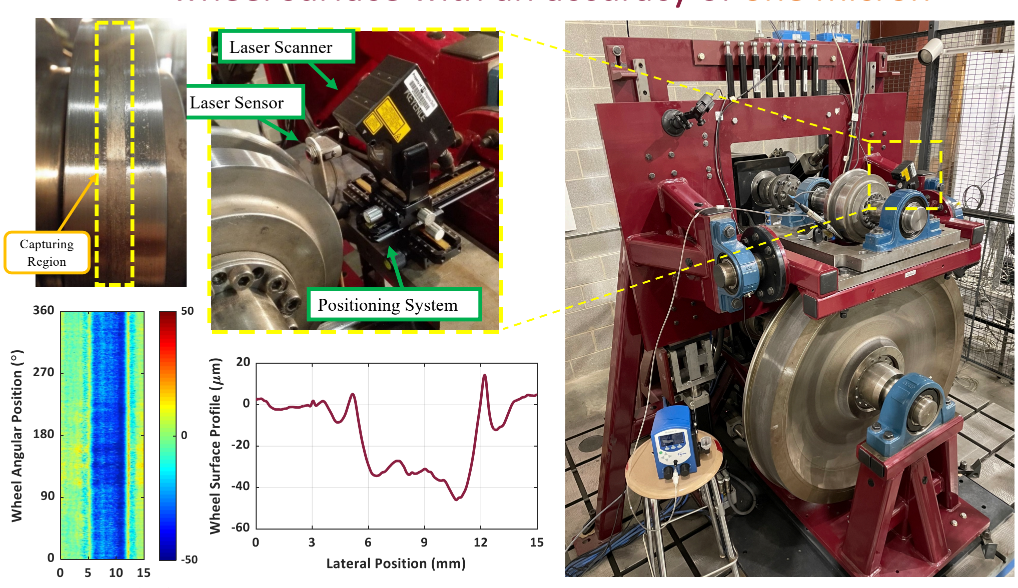
- Six linear actuators control
  - Wheel Load
  - Angle of Attack (AoA)
  - Lateral Displacement
  - Cant Angle



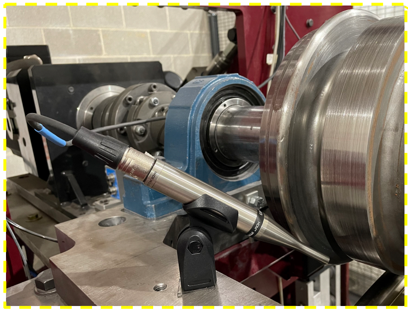


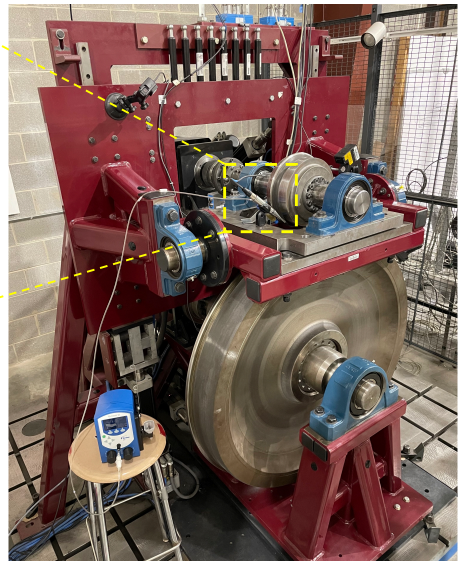
See VT-FRA Roller Rig Video

A precise laser scanner system measures the changes on wheel surface with an accuracy of one micron



The rig is equipped with a sound measurement system to record sounds including wheel squeal



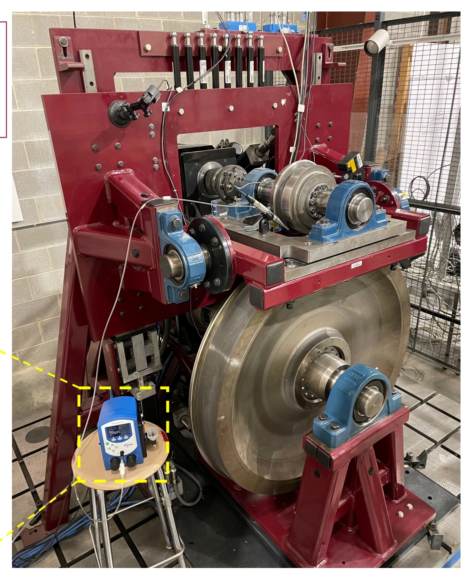


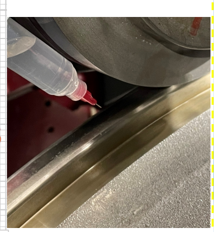
A instrument-grade microphone enables measuring sound emitted from the wheel-rail contact, including wheel squeal

A high-precision liquid dispensing system is integrated into the rig to accurately control the amount of applied 3rd body

- Some tests require applying 3rd body layers such as Top of rail friction modifiers, water, oil, etc. before or during the tests
- A Nordson Ultimus II Precision Fluid Dispenser is integrated into the roller rig for applying 3rd body layers

Parameter	Specification
Time range (s)	0.0001 – 999.9999 seconds Accuracy: Within ±0.05% of the selected time setting Repeatability: Less than 16 μsec at any time setting
Air Pressure Output	0 - 15 psi Accuracy: ±0.3 psi





VIRGINIA TECH

Various studies have been performed using the roller rig, for improving our underrating of some of the elements that can improve railroad operational efficiency and safety

Task Description	Status
1. Experimental Evaluation of the Contact Patch Geometrical Shape and Dimensions	Completed
2. Evaluating the Effect of Natural Third-Body Layers on Rolling Contact	Completed
3. Evaluating the Effect of Angle of Attack on Contact Dynamics	Completed
4. Validation of Creep Force Theories Such as CONTACT (by Dr. Edwin Vollebregt)	Completed
5. Evaluating the Effect of ToR Friction Modifier on Contact Mechanics and Dynamics	Completed
6. Evaluating the Effect of Cant Angle on Rolling Contact	Completed
7. ~~Validation of Friction Measurement Tools Commonly used by the Railroad Industry~~ Evaluating the Effect of Applied Third-Body Layers on Rolling Contact	Completed
8. Recommendation and Documentation	In Progress

VIRGINIA TECH

Although Top of rail friction modifiers (TORFM) are widely used by railroad industry, some of their long and short effects remain unknown

"I am spending more than $20M on this goop and do not know if I am using too much or too little"

VIRGINIA TECH

Some of the uncertainties are influenced by lack of data from controlled and repeatable conditions

Potential Benefits

- TORFM reduces wheel/rail wear while maintaining an intermediate traction coefficient [1,2]
- TORFM improves low traction issues, such as those caused by leaf residue contaminations [3,4]
- TORFM reduces squeal noise during curving [5,6]
- TORFM's carry distance 1 – 5 miles, claimed by the manufactures [1,2]

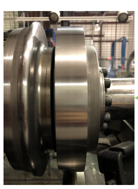
Potential side effects

- Large hard particles [3,4] and metal composition [7] in TORFM could cause cohesive wear and damages
- Hard to stabilize the traction coefficient in a fixed range for multiple TORFMs tested [7]
- Squeal noise can also occur at the same amplitude due to the negatively sloped instantaneous creep curves [8]
- Much shorter carry distance (70 – 450 m) by analyzing the surface deposits on top of rail using dispersive X-ray [9]

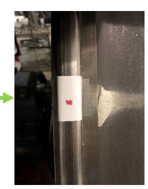
[1] Whitmore. Technical Data Sheet - TOR Armor Friction Modifier. 2021.
[2] LBFoster. Technical Data Sheet - KELTRACK Trackside Freight. 2016.
[3] Li Z, Arias-Cuevas O, Lewis R, Gallardo-Hernández EA. Rolling–Sliding Laboratory Tests of Friction Modifiers in Leaf Contaminated Wheel–Rail Contacts. Tribology Letters. 2008
[4] Arias-Cuevas O, Li Z, Lewis R, Gallardo-Hernández EA. Rolling–sliding laboratory tests of friction modifiers in dry and wet wheel–rail contacts. Wear. 2010
[5] Eadie DT, Santoro M, Kalousek J. Railway noise and the effect of top of rail liquid friction modifiers: changes in sound and vibration spectral distributions in curves. Wear. 2005
[6] Eadie DT, Santoro M. Top-of-rail friction control for curve noise mitigation and corrugation rate reduction. Journal of Sound and Vibration. 2006
[7] Messaadi M, Oomen M, Kumar A. Friction modifiers effects on tribological behaviour of bainitic rail steels. Tribology International. 2019
[8] Liu X, Meehan PA. Investigation of squeal noise under positive friction characteristics condition provided by friction modifiers. Journal of Sound and Vibration. 2016
[9] Khan SA, Lundberg J, Stenström C. Carry distance of top-of-rail friction modifiers. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. 2018

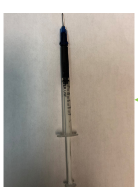
Objective: Evaluate the short- and long-term effect of TORFM on traction and wear

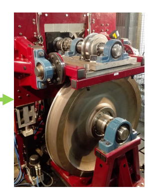
Different amounts of TORFM are applied in precise amounts at the W/R contact in controlled tests

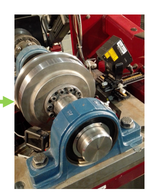


1. Carefully Redress Wheel Surface
2. Accurately Locate Contact Patch
3. Precisely Apply TOR Friction Modifier
4. Perform Highly Controlled Experiment
5. Thoroughly Clean Third Body Layers
6. Precisely Measure Wheel Surface Change





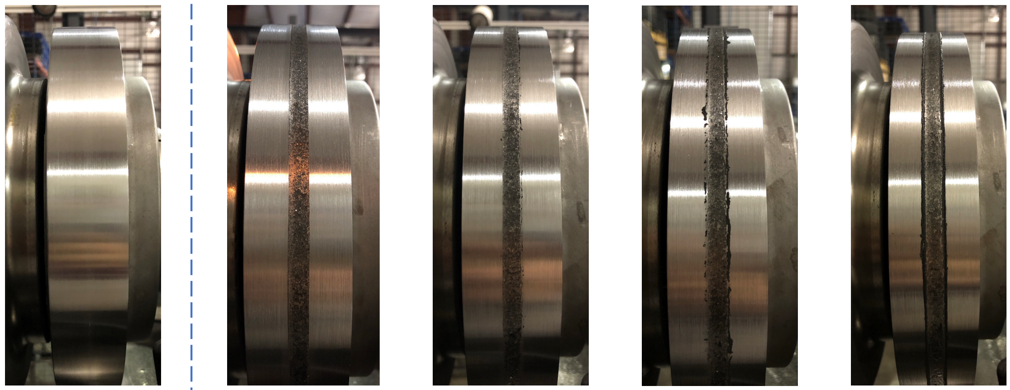




VIRGINIA TECH

Surface condition before and after 60 minutes of testing for different amounts of TORFM

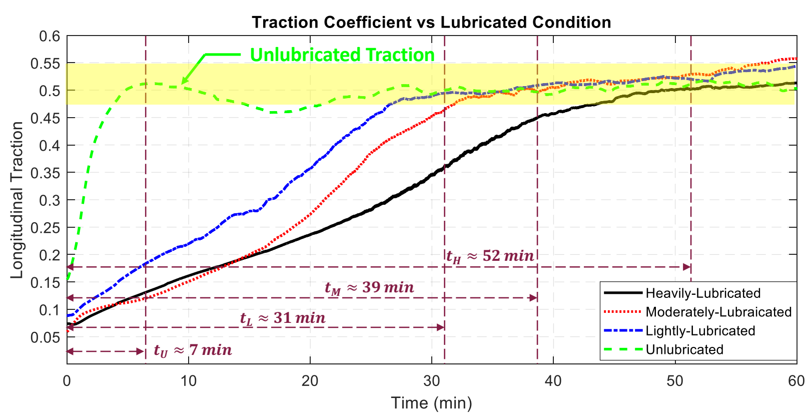
Carefully Redressed Wheel Surface	Condition 1: Unlubricated	Condition 2: Lightly-Lubricated	Condition 3: Moderately-Lubricated	Condition 4: Heavily-Lubricated



Initial Surface Condition	TORFM = 0 cc	TORFM = 0.02 cc (1X)	TORFM = 0.10 cc (5X)	TORFM = 0.50 cc (25X)

VIRGINIA TECH

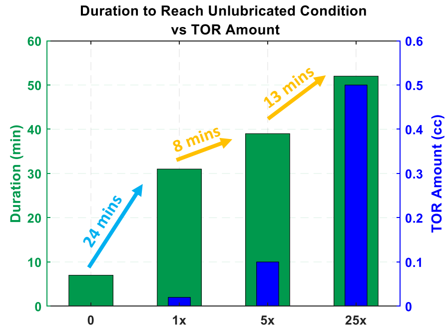
Increasing TORFM prolongs returning to unlubricated condition (prolongs TORFM longevity) nonlinearly

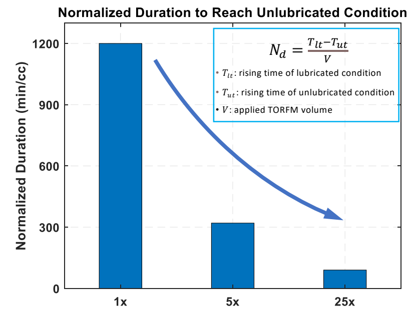


- For unlubricated condition, traction increases rapidly
- Friction modifiers reduce the rate of increase in traction
- Traction coefficient increases nonlinearly with increasing amount of TORFM
- It takes 31, 39, and 52min for the lubricated condition to return to unlubricated condition

Increasing TOR volume prolongs the lubricated condition some, but not proportional to the increase in material application

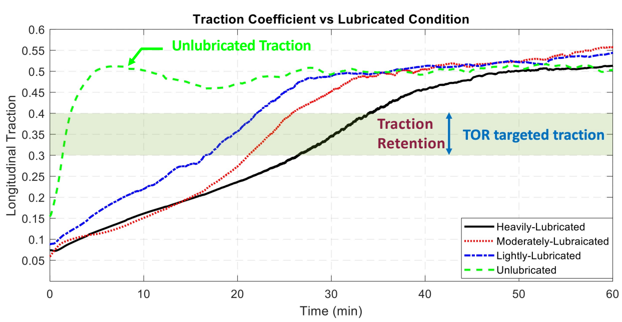
(i.e., a five-fold increase in TOR does not cause 5 times longer lubricated condition)

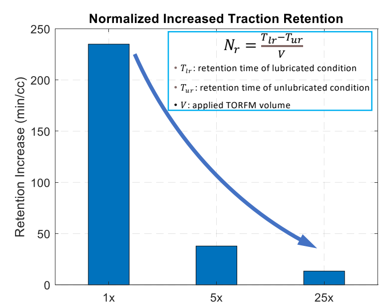




- U-L⇔L-L: the duration to return to unlubricated condition increases by 24 mins with **1x** TOR
- L-L⇔M-L: the duration to return to unlubricated condition increases by 8 mins with **5x** TOR
- M-L⇔H-L: the duration to return to unlubricated condition increases by 13 mins with another **5x** TOR
- The best cost/benefit is achieved with light lubrication

Light lubrication provides the most favorable cost-to-benefit ratio in terms of increased traction retention

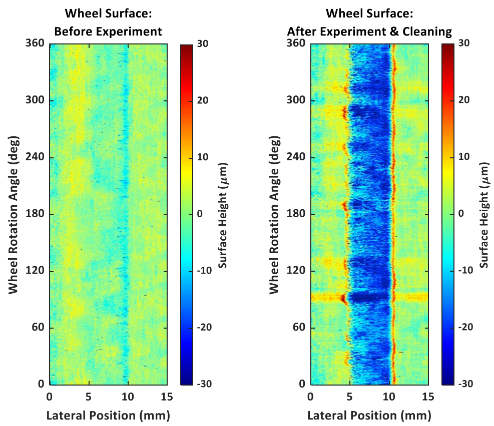


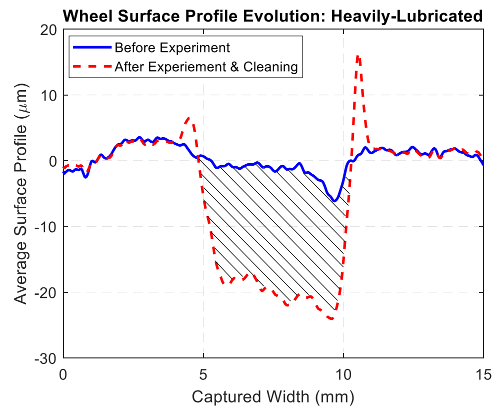


- TORFM is intended to provide an intermediate adhesion coefficient between 0.3 and 0.4 [1]
- The capability of maintaining traction in this range is defined as traction retention [2, 3, 4]
- The traction retention duration is extended by TORFM but doesn't change significantly with increasing TORFM
- The best cost/benefit in terms of increased traction retention is achieved with light TORFM lubrication

[1] Technical Data Sheet of Whitmore TOR Armor
[2] Lewis SR, Lewis R, Olofsson U, Eadie DT, Cotter J, Lu X. Effect of humidity, temperature and railhead contamination on the performance of friction modifiers: Pin-on-disk study. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. 2013.
[3] Buckley-Johnstone L, Harmon M, Lewis R, Hardwick C, Stock R. A comparison of friction modifier performance using two laboratory test scales. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. 2019.
[4] Magel EE. A survey of wheel/rail friction. United States. Federal Railroad Administration. Office of Research, Development, and Technology; 2017.

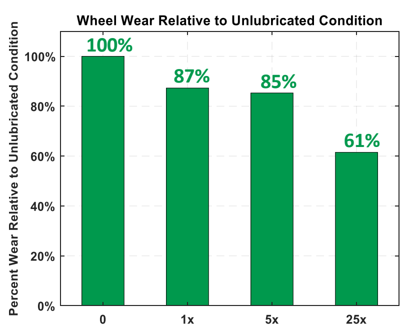
Wheel wear is measured for various volumes of TOR, using a laser surface profiler

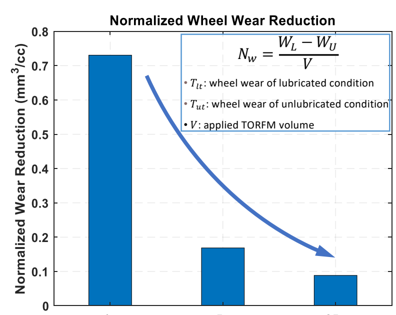




- The integrated laser scanner enables measuring wheel surface condition with micron accuracy
- Wheel wear is measured as the change in surface profile before and after experiments

Lubricated conditions reduce wheel wear by 15 - 40% during the 60-min experiments





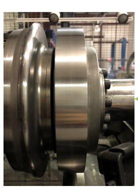
- Heavily-lubricated condition has an approximately 40% wear reduction
- Moderate and light amount of TOR have nearly the same effect on wheel wear
- The best cost/benefit is achieved with light lubrication
- More experiments in shorter durations are needed to better understand wear progression (planned for the future)

How does traction behave after multiple TORFM applications?

- What we have investigated in Phase I experiment:
  - Compare traction progression between TORFM lubricated and unlubricated conditions starting with a redressed wheel
  - Investigate TORFM's longevity, traction retention, and wheel wear reduction in various TORFM lubrication conditions
- What we haven't explored:
  - How does the traction in various lubricated conditions behave if natural third body layers are initially present?
  - How does the traction evolve after multiple applications of TORFM?

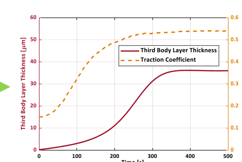
Additional Tests

Different amounts of TORFM are applied to the contact patch after natural third body layer saturates in controlled experiments

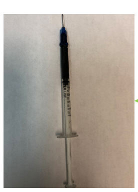


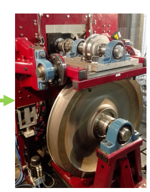
Carefully Redress Wheel Surface

<u>Cycle 0</u>: Run the Experiment in Unlubricated Condition to Build Up Natural 3rd BLs



Radmehr, "Experimental Evaluation of Wheel-rail Interaction", 2020



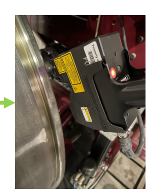


<u>Cycle 1</u>: Apply TOR on Roller Surface

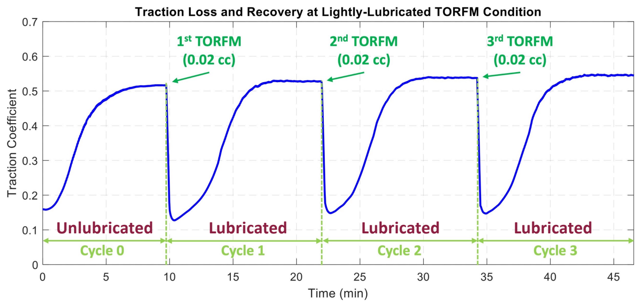
<u>Cycle 2</u>: Apply TORFM Again When the Traction Returns Steady

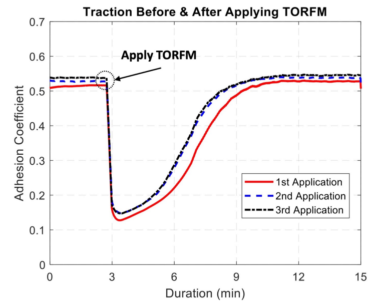
<u>Cycle 3</u>: Repeat the Previous Procedure When the Traction Returns Steady

Measure Wheel/Roller Surface at the End of the Experiment



Light TORFMs with natural third body layer provide a stable traction evolution



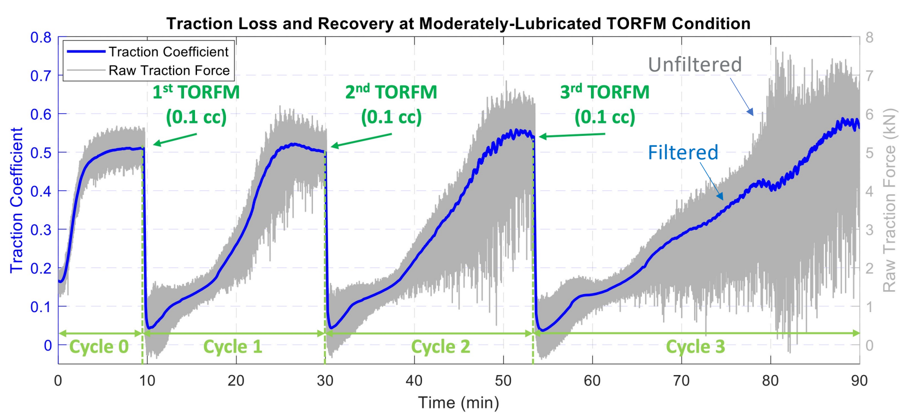


- Applying light amount of TOR causes a rapid drop in traction, followed by a graduate rise to unlubricated condition after time
- Traction coefficient return to unlubricated condition for 1st TORFM is slightly longer than the 2nd and 3rd applications
  - The initial condition for 1st TORFM application with natural 3rd body only
  - The initial conditions for 2nd and 3rd applications have natural 3rd body and TOR dry residue

Slide 23

Jan-26-2022

Applying a large volume of TORFM causes a larger reduction in traction for a more prolonged period of time – some evidence of stick-slip is observed in the data and roller surface marks

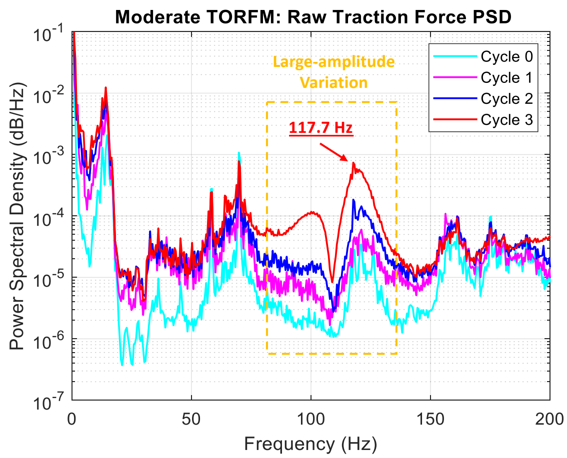


- Similar to the light application, an immediate drop in traction is observed
- The return to unlubricated condition is prolonged with successive application of TOR
- Increasing high frequency content is observed with successive application of TOR

Slide 24

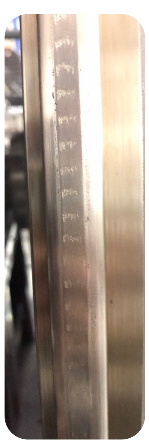
Jan-26-2022

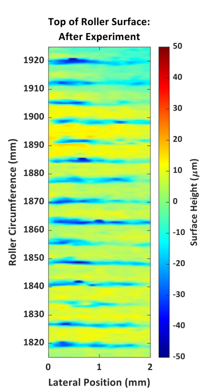
The PSD peak at 117.7 Hz increases in magnitude and breadth with successive TOR application



- The increase in PSD peaks is most noticeable between in the range of 80 and 140 Hz
- In this range, the peak at 117.7 Hz is the tallest among others

The (temporal) frequency of shiny marks on the roller are nearly the same as the 117.7 peak observed in the PSD plot





- Roller speed: 3 km/h = 833 mm/s
- Corrugation's wavelength = $\frac{Length}{Cycles} = \frac{100\ mm}{14\ cycles} = 7.14$ mm
- Corrugation's frequency = $\frac{Speed}{Wavelength} = \frac{833\ mm/s}{7.14\ mm}$ = **117 Hz**

- The roller markings were observed after the 3rd cycle of the tests with 0.1cc TOR
- The markings indicate stick-slip occurring between the wheel and rail
- We believe this is induced by the high %creepages (2% for the tests) and large reduction in traction

More is not necessarily better!

- Light TORFM lubricated condition potentially provides the most favorable cost-to-benefit ratio, in terms of TORFM longevity, traction retention, and wheel wear reduction
- Applying more TORFM doesn't bring added benefits since some of the TOR material is pushed out of the contact band
- Under high traction condition, excessive TOR could induce stick-slip, potentially causing wheel and rail surface degradation
- Recommendations:
  - Conduct controlled field studies that can further verify the lab tests
  - Consider applying less TOR with more frequency, particularly in high-traction conditions such as grade approaches, grade descends, etc.

VIRGINIA TECH

Thank You!