Wheel squeal and flanging noise

Challenges in validation of friction management in the field and laboratory

Dr. J.Paragreen - LB Foster

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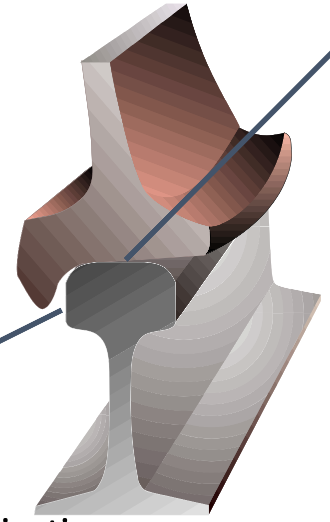
Friction Management – Guiding Principles



> **Top of Rail (TOR) / Wheel Tread Friction Modifier**
TARGET: COF ~ 0.35
> Typical dry 0.6
> Impacts:
- Rail / Wheel Wear
- RCF Development
- Top of Rail Noise
- Corrugations
> Reduced lateral forces
> Switch protection
> Reduced traction energy consumption

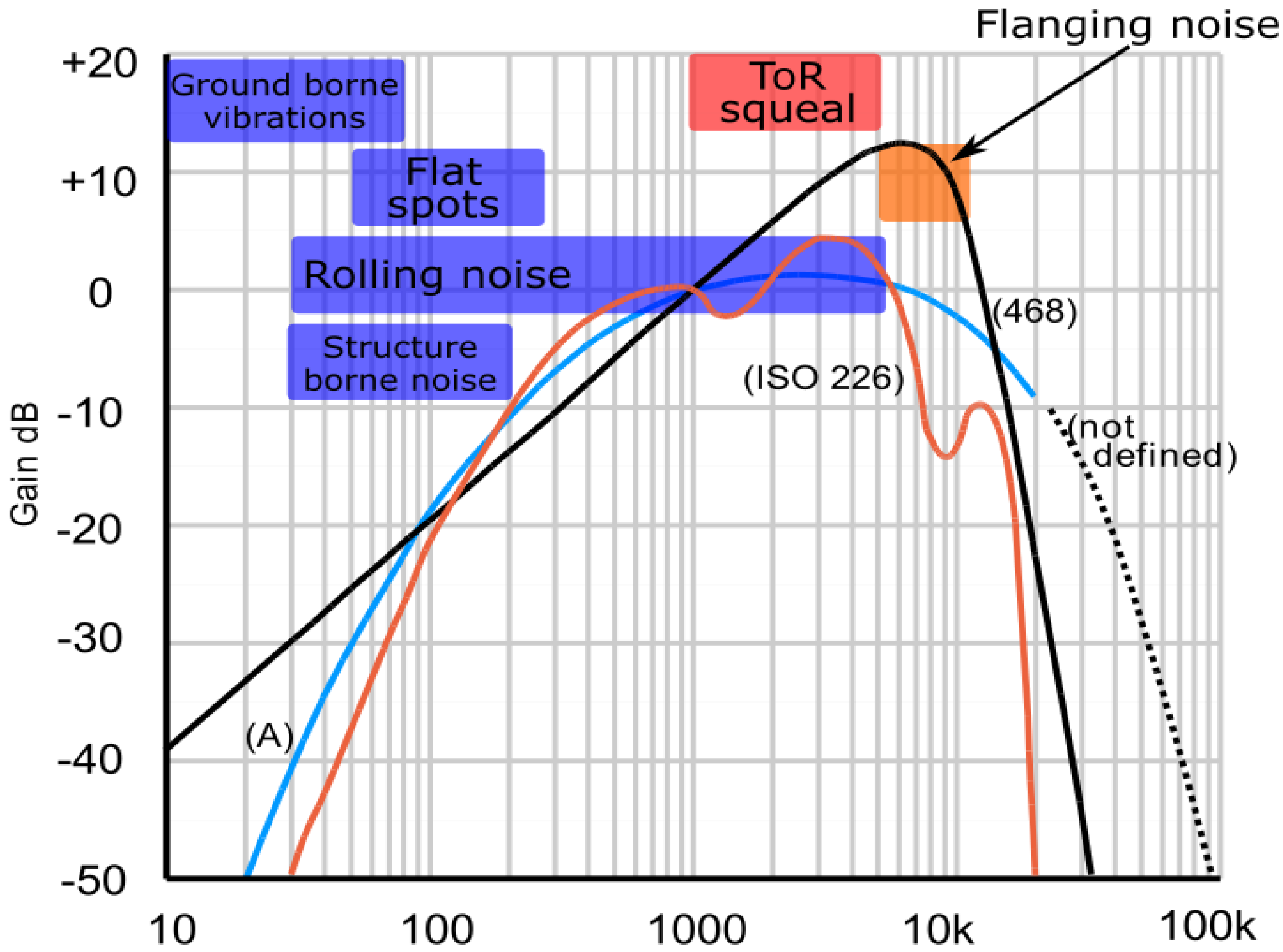
> **Gauge Face (GF) / Wheel Flange lubrication**
TARGET: COF < 0.15
> Impacts:
- Rail / Wheel Wear
- Gauge Corner Cracking
- Flange Noise
- Derailment Potential (Wheel Climb)

Background to rail wheel noise

Noise: Spectral ranges

Noise Type	Frequency range [Hz]
Rolling	30 – 2500
Rumble (including corrugations)	200 – 1000
Flat spots	50 – 250 (speed dependant)
Ground Borne Vibrations	30 – 200
Top of rail squeal	1000 – 5000
Flanging noise	5000 – 10000

Human perception of noise



ITU- R 468 (blk), A-weighting (blue), and inverse ISO 226 (2003) (red)

Squeal and Flanging Noise

Top of rail wheel squeal noise

- High pitched, tonal squeal (predominantly 1000 – 5000 Hz)
- Prevalent noise mechanism in "problem" curves, usually < 300m radius
- Related to both negative friction characteristics of Third Body at tread / top of rail interface and absolute friction level
  - Stick-slip oscillations
  - Leading wheelset, inside wheel

Flanging noise

- Typically a "buzzing" OR "hissing" sound, characterized by broadband high frequency components (>5000 Hz)
- Affected by:
  - Lateral forces: related to friction on the top of the low rail
  - Flanging forces: related to friction on top of low and high rails
  - Friction at the flange / gauge face interface

Corrugation noise

Noise due to corrugation with occasional wheel squeal and flanging noise

Corrugation noise

- **Low pitched rumbling noise due to the presence of corrugation on the running band of the rail**

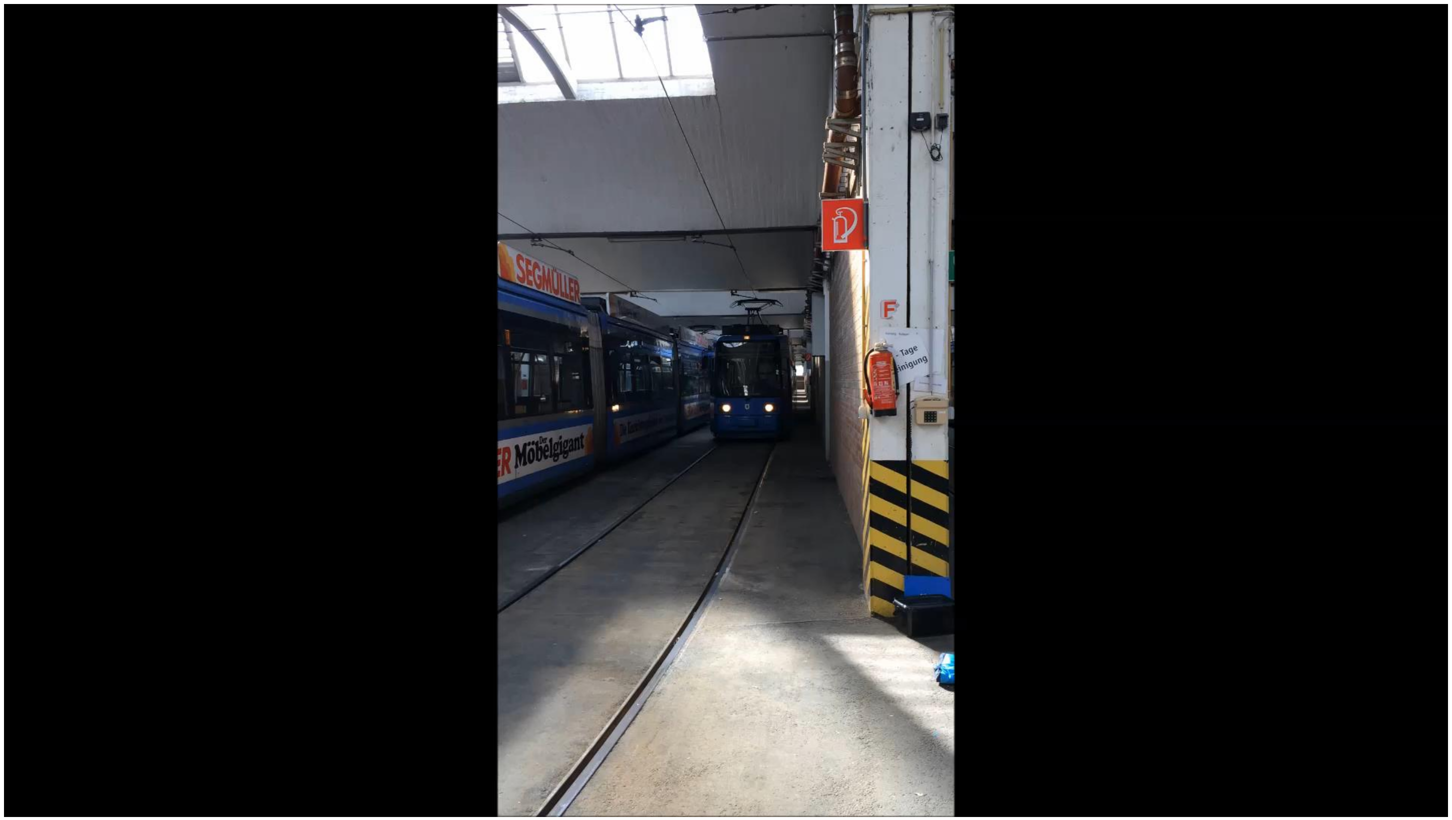
Field trials

FM Focus: Noise/Corrugation

Baseline – **No TOR FM** application

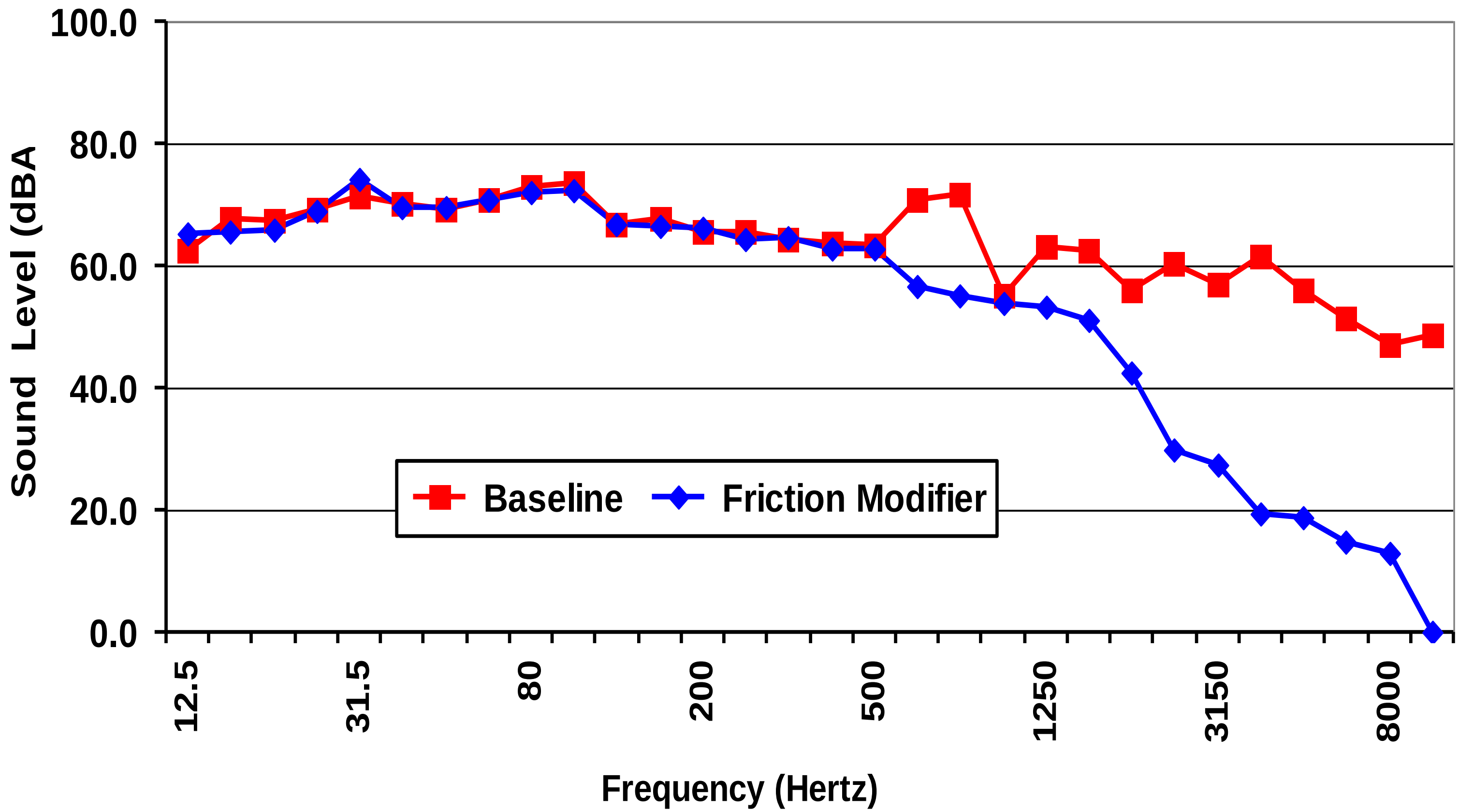
FM Focus: Noise/Corrugation

AFTER TOR FM application - manual



Spectral sound distribution: Trams

> Effects of frictional conditions



Spectral sound distribution: Trams

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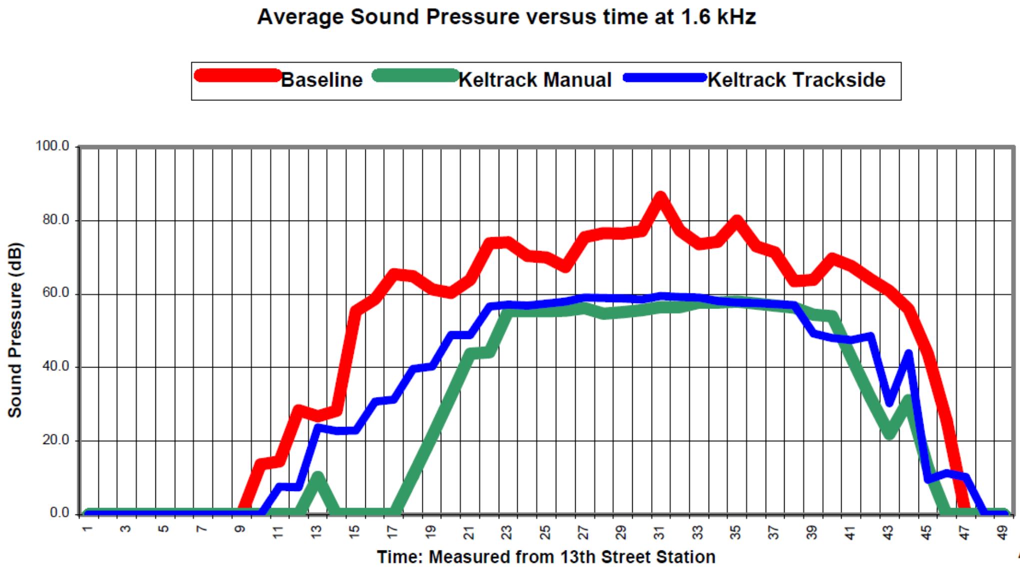
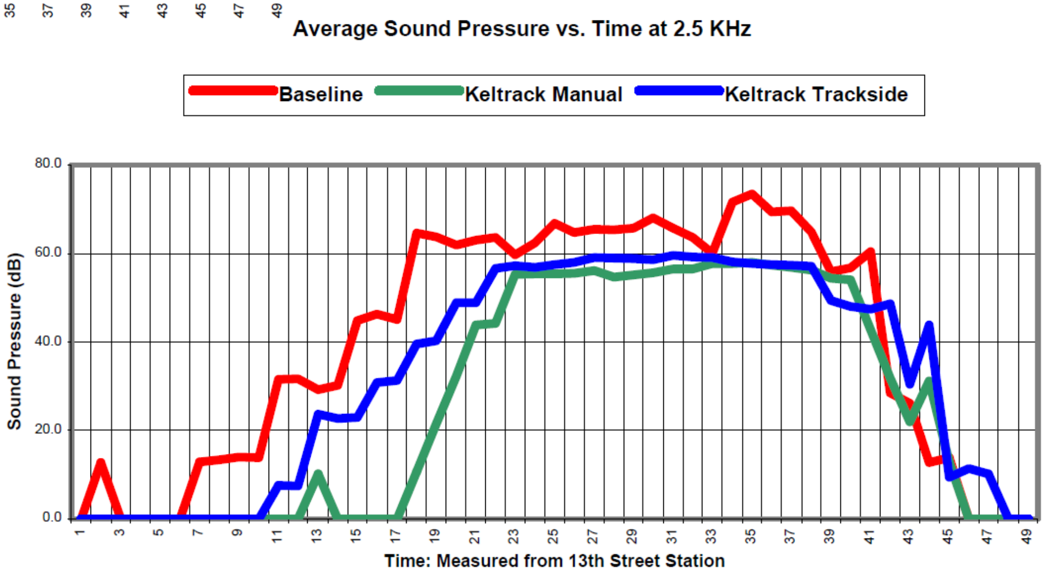




Field trials

> Typical field trials compare baseline measurement to application of top of rail materials

> Noise can be very specific to:

- Vehicle
- Bogie steering – primary yaw stiffness
- Wheel profile
- Location – curve/cant
- Running speed
- Weather
  - Rain and moisture (morning dew) particularly large impacts
  - Humidity
- Rail and wheel contamination
- Measurement location (reflections)

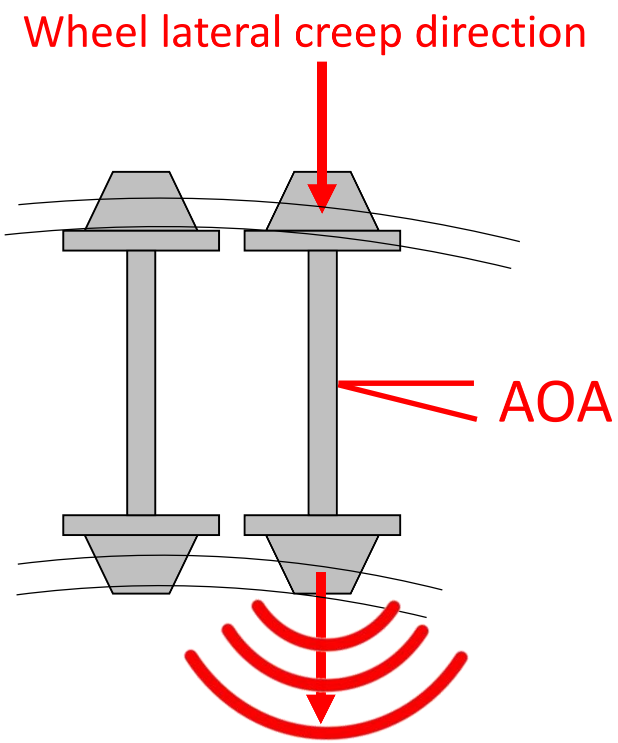
> Don't necessarily get squeal from every bogie

Wheel squeal – conventional theory

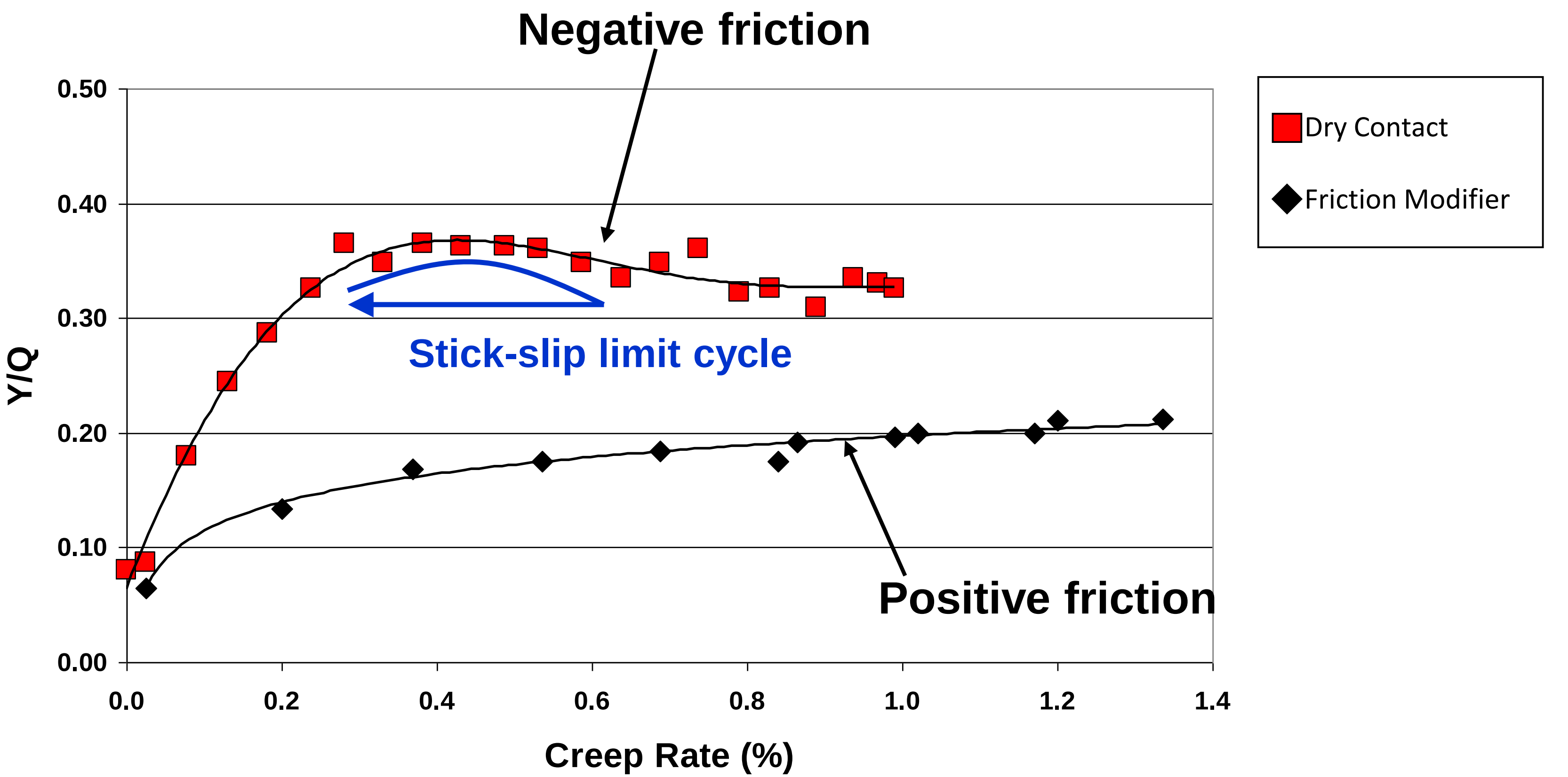
Lateral creepage of the wheel - prime cause of squeal

- Particularly for the leading inner wheel of a bogie
- stick-slip mechanism of this creep force

Rudd 1976, Remington 1985

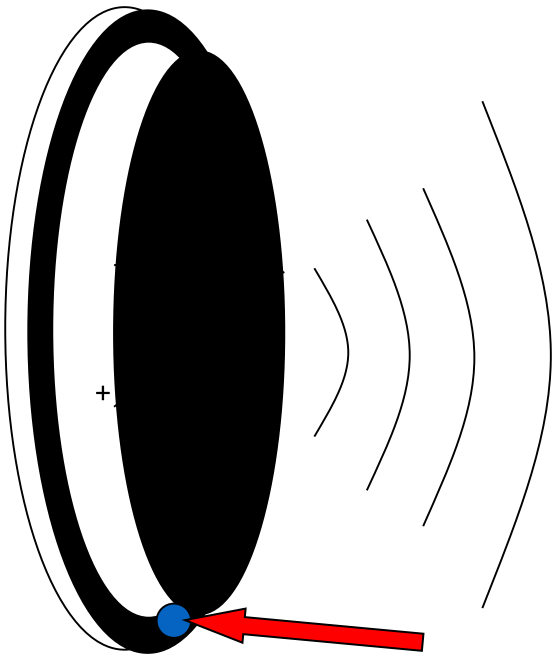


Absolute Friction Levels and Positive/Negative Friction – conventional theory



*** Replotted from: "Matsumoto a, Sato Y, Ono H, Wang Y, Yamamoto Y, Tanimoto M & Oka Y, Creep force characteristics between rail and wheel on scaled model, *Wear,* Vol 253, Issues 1-2, July 2002, pp 199-203.**

Absolute Friction Levels and Positive/Negative Friction – conventional theory



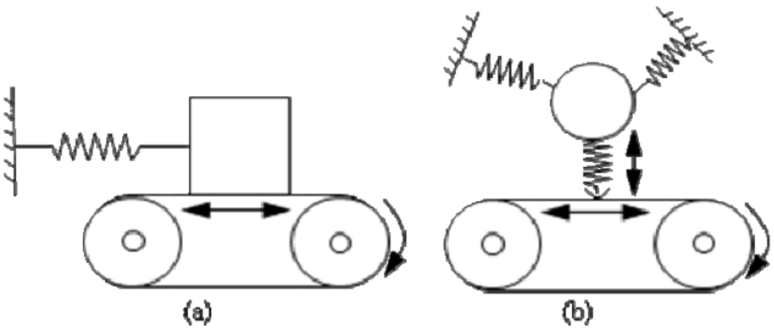
Frequency response of the wheel

Mode Coupling Instability Mechanism

> Jiang, Anderson and Dwight, 2015
> Further analysis by Bo Ding 2018

Theory:

> Based on commonly accepted theory for squeal in braking systems. A coupling of vibration in two different directions
> Wheel/rail interface subject to vertical and lateral vibrations and forces



Alternative theory

Mode Coupling Instability Mechanism

- The lateral frictional force between the wheel and the rail is related to the normal (vertical) force, so a natural coupling

- $F = \mu N$

- If wheel vertical and lateral vibration frequency modes are close
- Then friction coefficient increases to a critical threshold,

  -> vertical and lateral oscillations become out-of-phase

  -> friction force, which depends on the vertical force, is therefore out-of-phase with the lateral motion => unstable positive feedback.

Alternative theory

> Mode coupling instability mechanism

> Curley, Anderson, Jiang and Hanson – track study

- Found noise from wheels on inner and outer rail
- Running bands in different locations on gauge corner of inner and outer rail
- Track form had an influence
- Found TOR FM had benefit when applied to both rails, but in some cases when applied to inner rail only no benefit
- Counter to normal theory gauge corner lubrication also had a benefit for wheel squeal

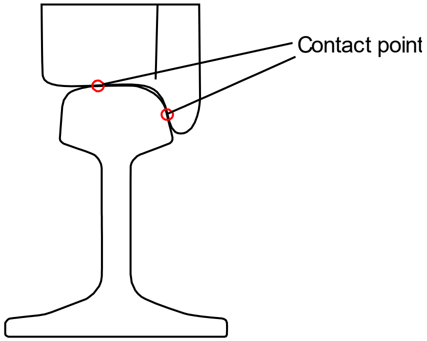
Alternative theory

>Mode coupling instability mechanism

- > For all these theories friction between the wheel and the rail still key.

- > Work carried out by Bo Ding 2018 – studied slip/stick mechanism, mode coupling instability, and third potential mechanism wheel rail coupling

- > 2 point contact – not studied much wrt wheel squeal

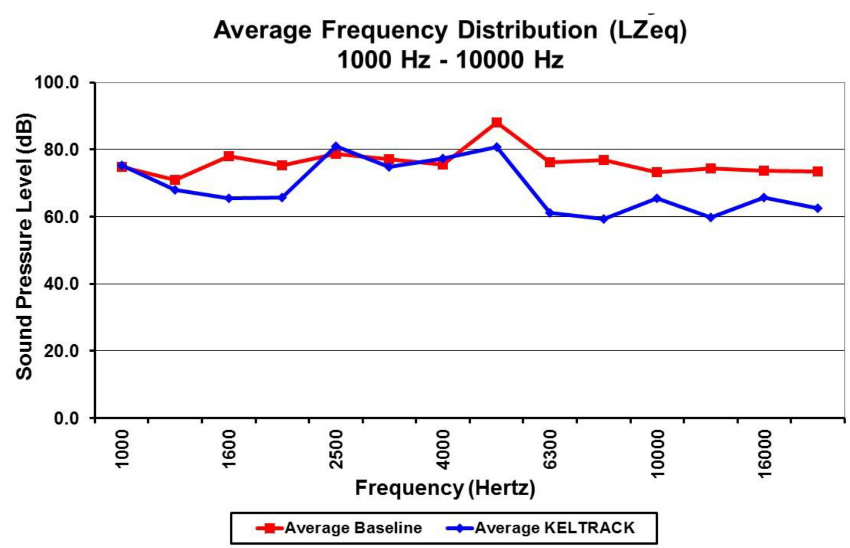


Freight trial with two types of water based TOR FMs

> Two versions of top of rail friction modifiers tested
  - Both products have high positive friction characteristics
  - Similar intermediate friction
  - Different binders and tackiness
  - One product retained more on wheel (less effective), other transferred more to rail
  - One product much more effective than the other in noise reduction

> Oil and grease based top of rail materials – difficult to balance noise reduction with braking and traction performance

> Difficult to predict noise performance from laboratory testing

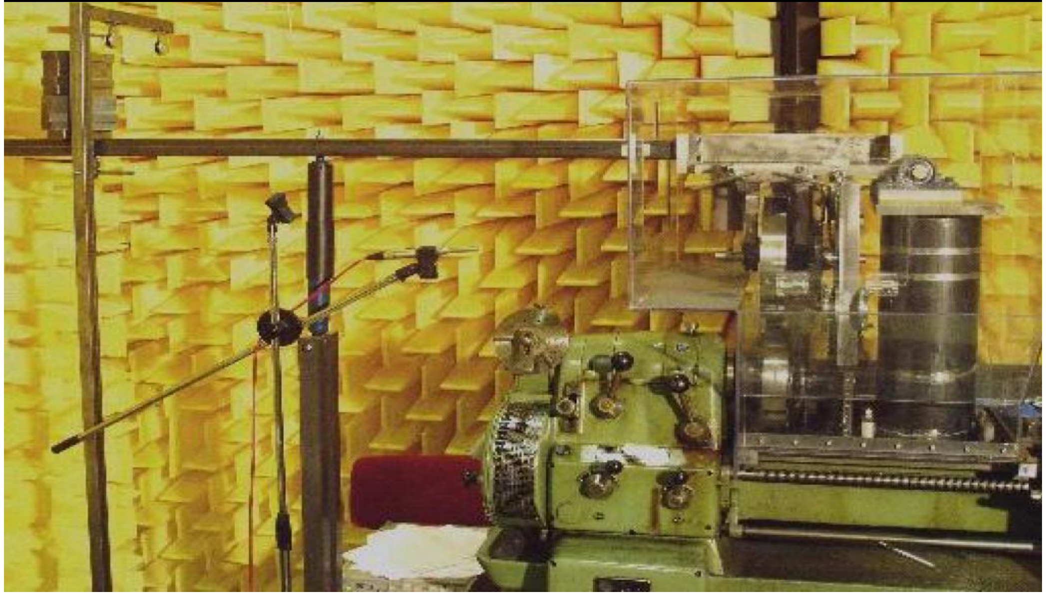


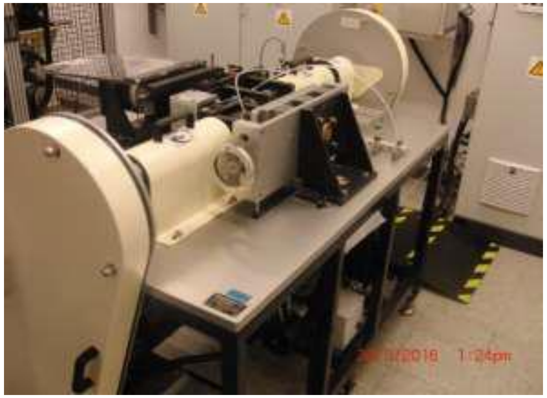
Laboratory investigations into wheel squeal

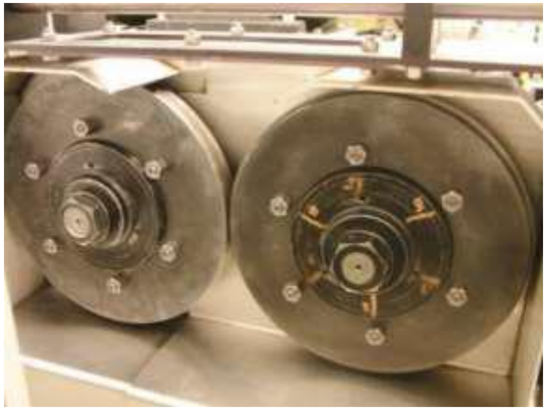
Laboratory testing

> Twin disc type testing

Eg. TNO test rig

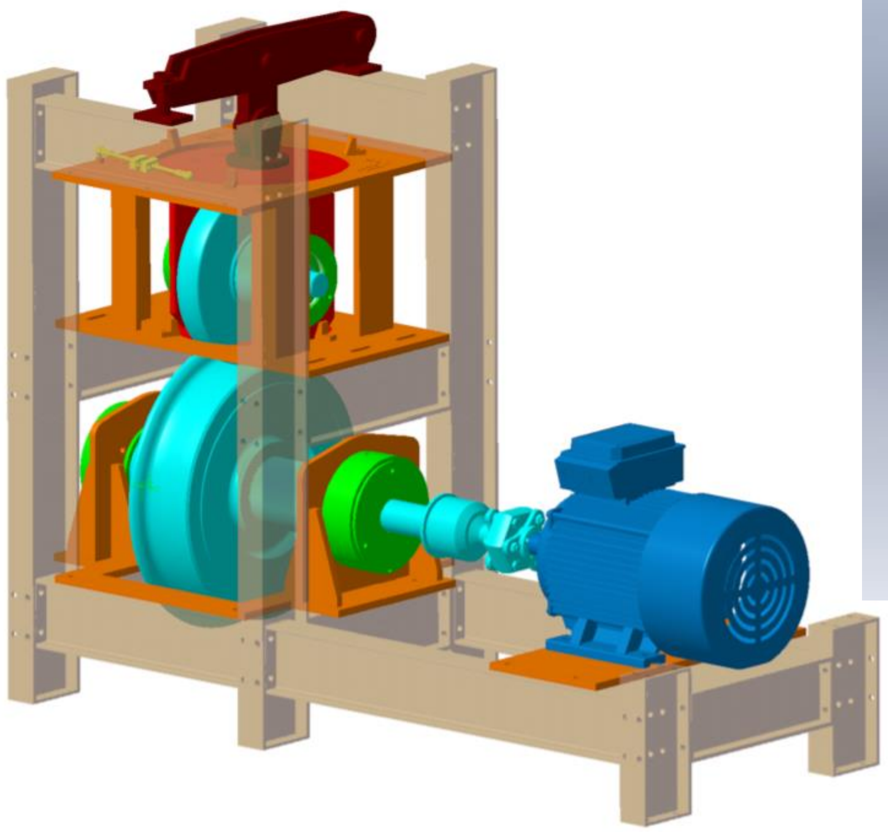


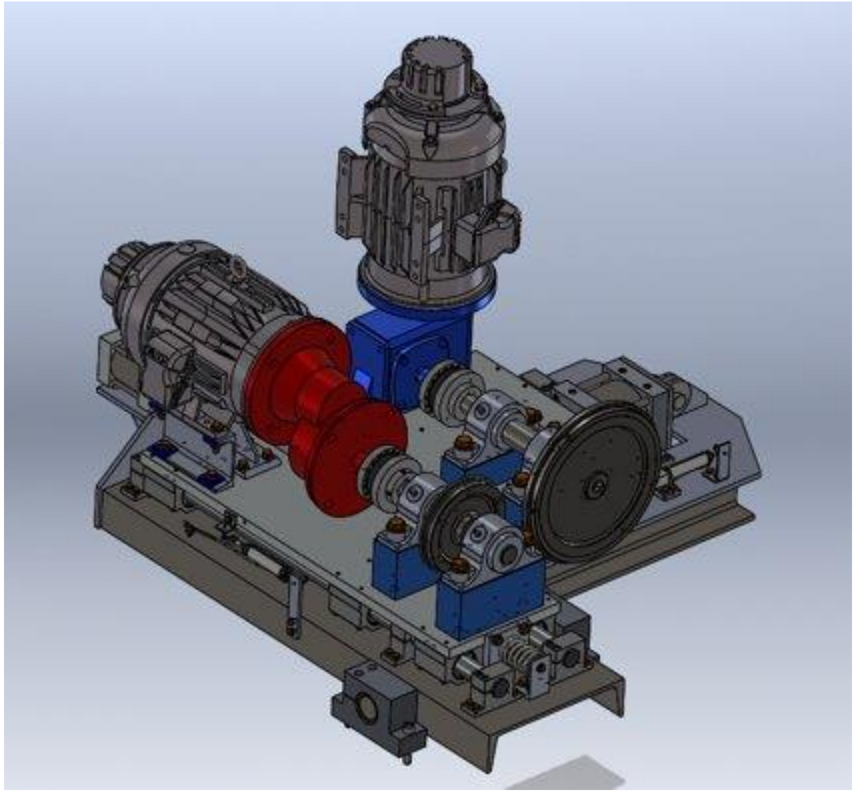




Laboratory testing

> Scaled rigs





Laboratory testing

> Full scale test rigs

Eg. DB full scale test rig

UIC study 2005

> Compared results wheel squeal mitigation of different products on laboratory test rigs and on site measurements
  - Issue of application rate, too

		TOR FM1 (water based)	TOR FM2 (oil based)	TOR FM3 (oil based)	TOR FM4 (oil based)	Water
Lab	TNO rig	Y	Y	Y	Y	
	DB rig	Y	Y			Y
Field	Site 1	Y	N	N	N	
	Site 2	N				
	Site 3	Y				Y

Comparison of wheel squeal for different FMs in lab and in the field – (Y – Noise reduced, N – no significant noise reduction)

Wheel squeal mitigation

> Good understanding of effective mitigation methods
- Top of rail/tread friction modifiers (lubrication) – all theories point to the importance of friction control
- Bogie/wagon design
  - Distance between axles
  - Vehicle steering – primary yaw stiffness
  - Wheel dampeners
- Wheel and rail profile
- Track form dynamics

Challenges

Product development

- Need on track trials and case studies to prove noise reducing properties.
- Lab scale test can give an indication – but not the whole story
  - Slows down product development – need to produce larger batches
  - Some products are easier to test by manual application than others
    - Eg on board - solid stick friction modifiers and lubricator sticks - to test in the field do you swap out the sticks from the whole fleet to negate the effect of other sticks on the performance? – In a smaller limited trial do you build up sufficient film thickness
- Need for better lab scale noise testing
- Understanding of required film thickness/application rate

End customer

- Needs case studies and evidence of on track performance
- Cannot rely on lab tests and friction data alone
- Squeal/noise remains a major issue for most railways/metros

“curve squeal remains one of the least understood railway noise sources despite the continuing efforts over recent decades” Jiang, Anderson and Dwight, 2015

Questions