Managing Rolling Contact Fatigue in Railways

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Outline

1. Identification
   - Inspection
2. Understanding
3. Treatments

1. Wheel and Rail Profiles
2. Rail grinding and Milling
3. Friction Management
4. Improved track geometry
5. Improved suspension trucks
6. Better steels
7. Inspection and defect detection and monitoring

IDENTIFICATION

RCF Defects

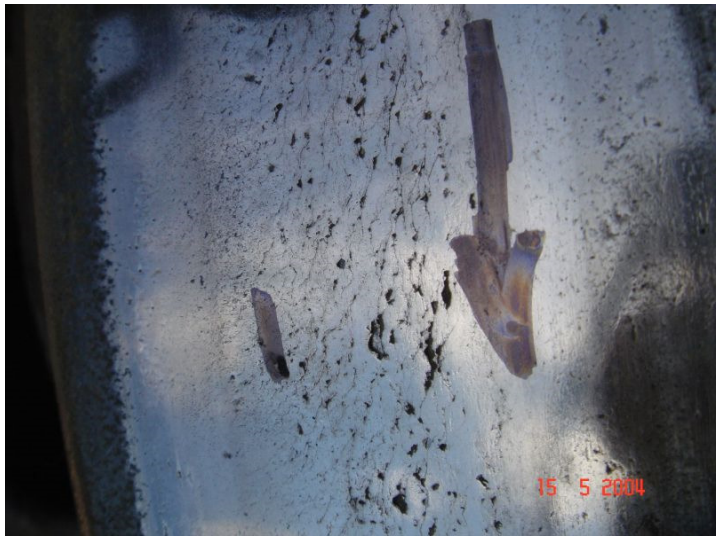
- Cracking (e.g. Head Checking)
- Shelling
- Deep Seated Shells
- Squats and Studs
- Crushed Heads

Light Cracking

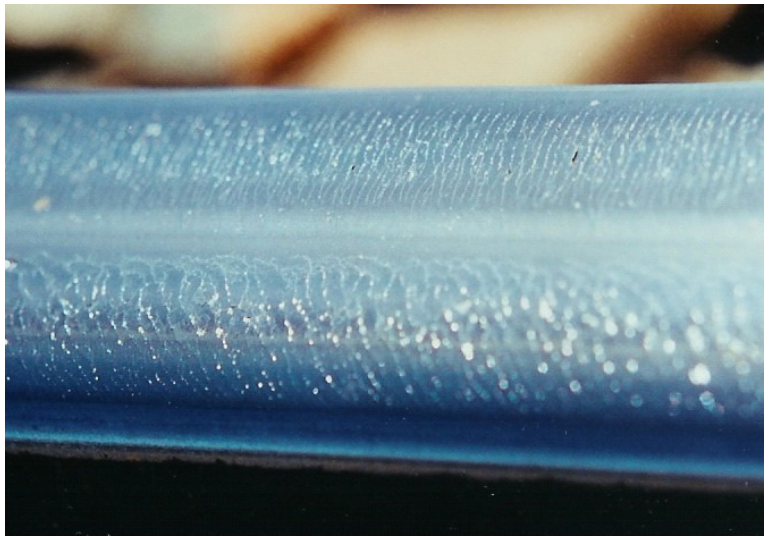
Micro-cracks on the field/rim side of the high-speed wheel.

Moderate checking at the gauge corner of the rail.

Intermediate Cracking



Well-defined cracks on the field/rim side of the wheel.



Crack orientation changes due to different creep directions of leading and trailing axles.

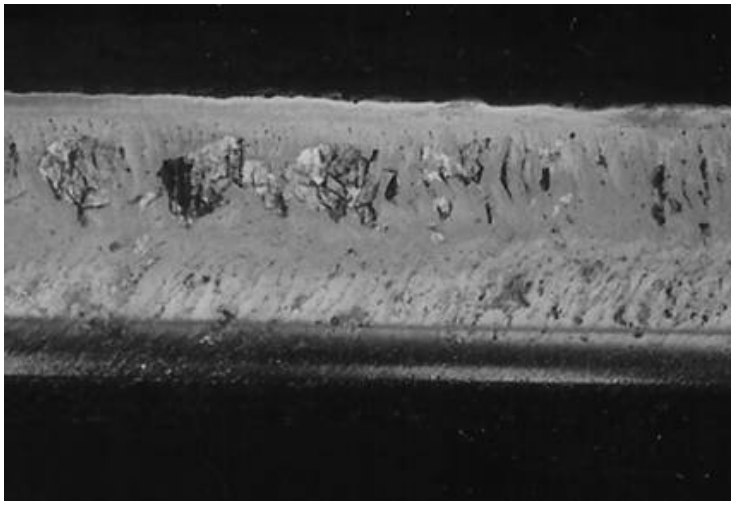
Heavy Cracking – Incipient Shelling

Deeper cracks on the field/rim side of the wheel tread with material starting to shell.

Incipient shelling on the rail.

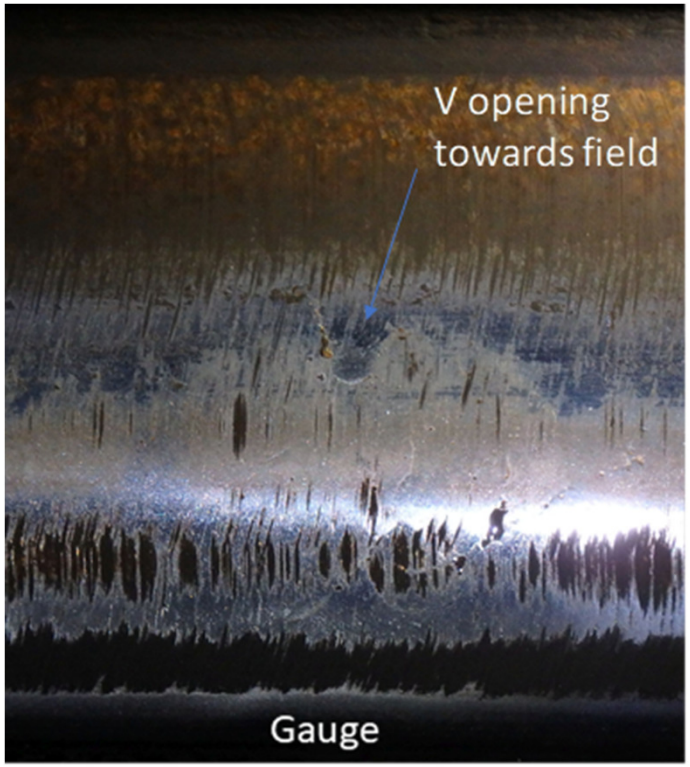
Shelling

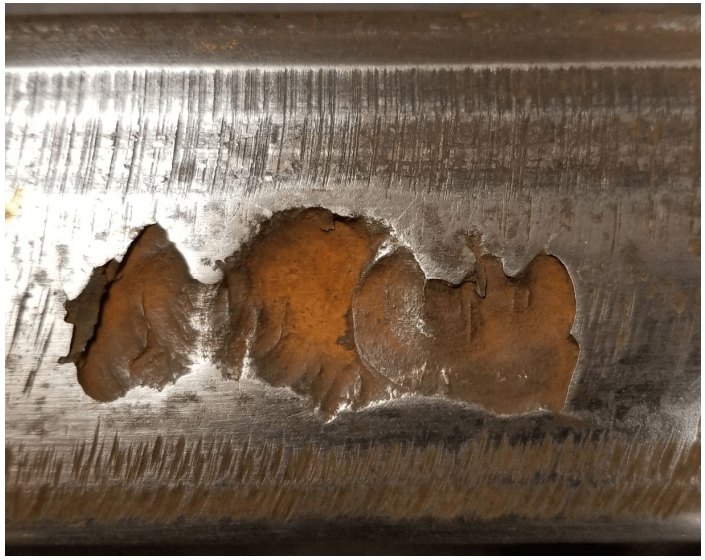
Continued propagation of cracks into the wheel surface leads to tread shelling.



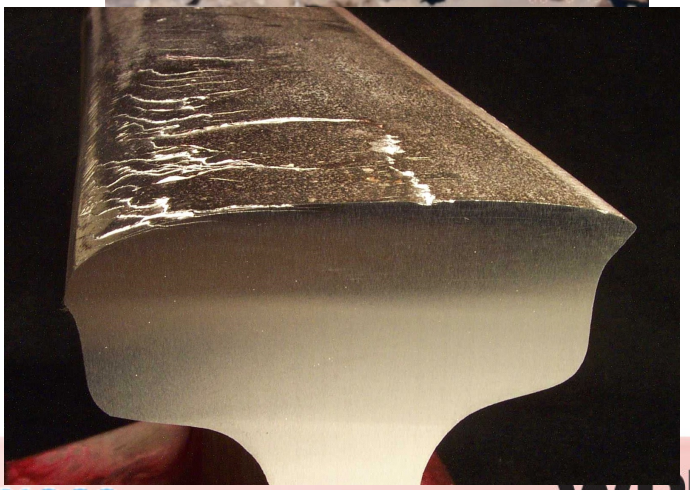
Alternating wet/dry conditions → shallow shelling.

(Rail) Squats/Dark-Spots/STUDS





Crushed Heads



Deep Seated Shells

gauge-corner collapse
in a dry environment

gauge-corner collapse
in a well-lubricated rail

transverse defect from
a shell.

INSPECTION / RECORDING

Human/Vision – hi-rail/vehicle borne

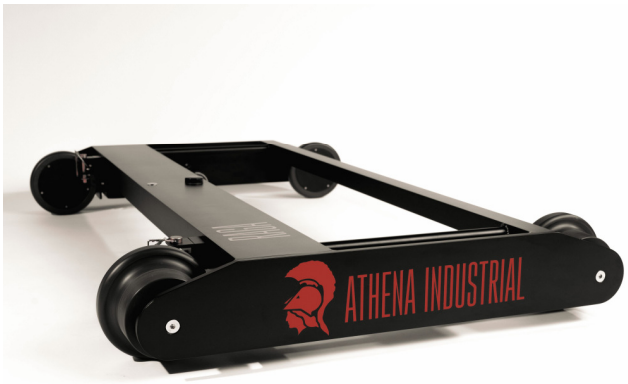
SOP meter

Electromagnetic

Rohmann Draisine
(eddy current)

MRX RSCM
(magnetic flux)

Goldschmidt



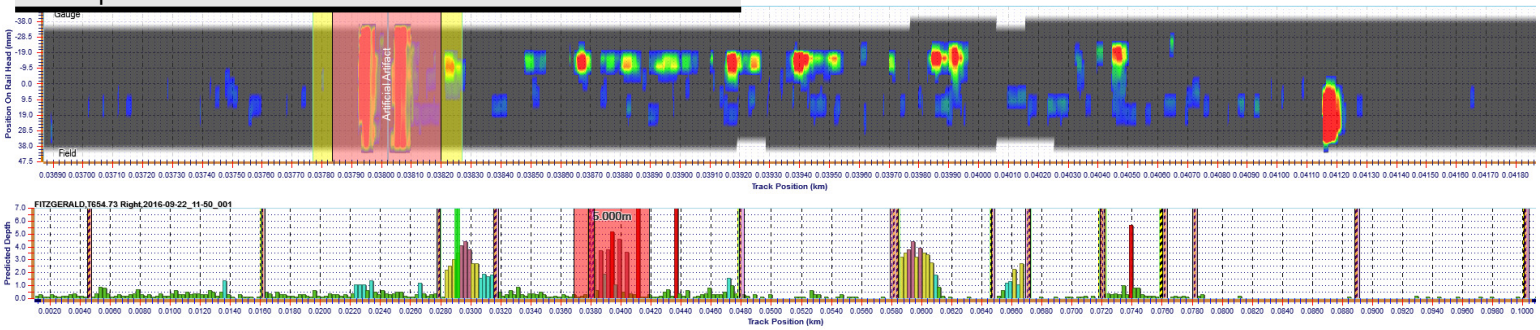
Athena

Vehicle towed electromagnetic

	
The MRX hy-rail RSCM unit	Rohman's hy-rail eddy current unit can have as many as 6 probes per rail. Running speeds are up to 40 mph.

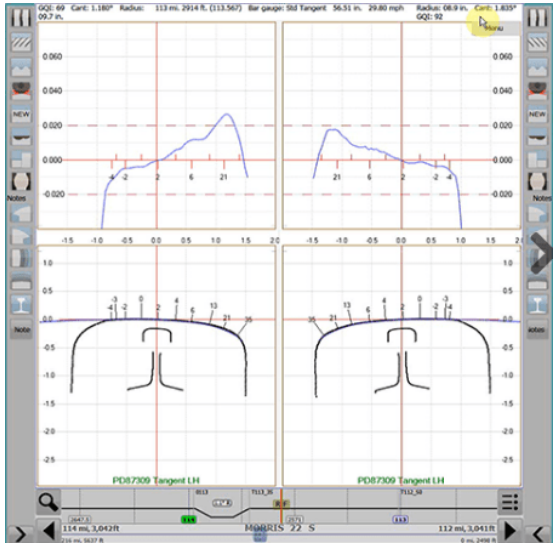
MRX Technology - RSCM

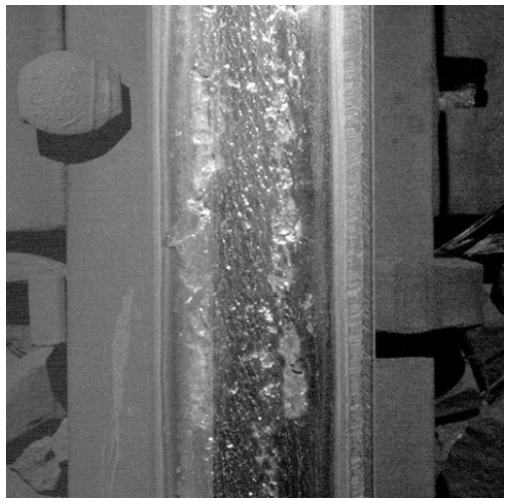
Specifications	
Technology	Magnetic flux leakage
Measures	Damage depth
In dense cracks	Deepest crack every 0.25 m
Range	7 mm
# of probes	19
Probe Spot size	5 mm
Operating speed	2-5 km/hr



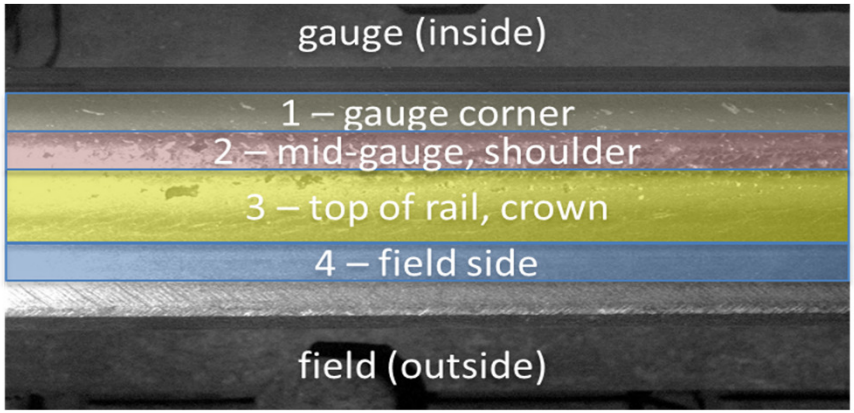
Machine Vision

- Loram RIV, ENSCO RSIS





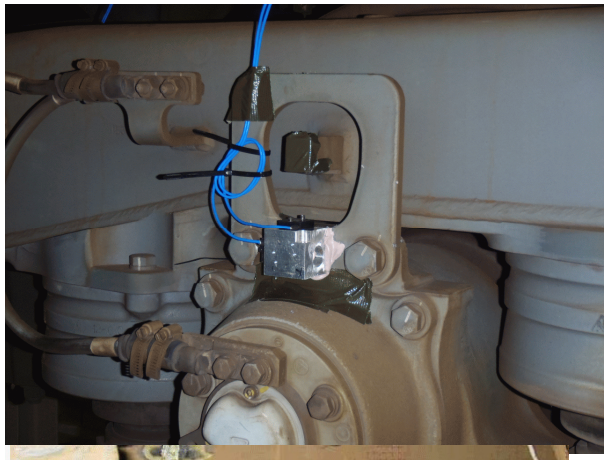
Surface Condition Scoring

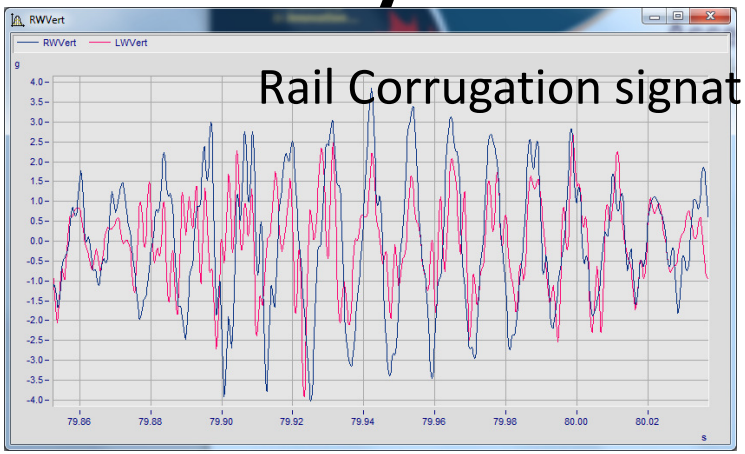


Surface Quality Index (SQI) with corrective actions

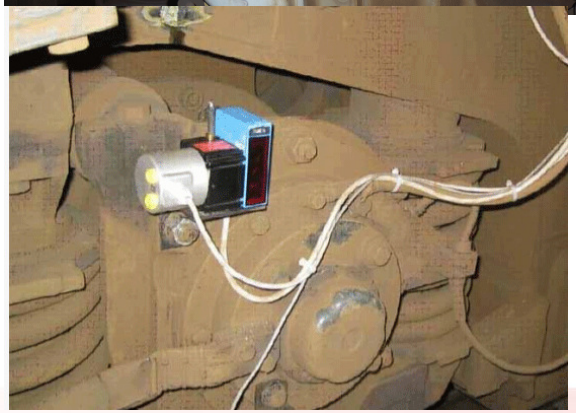
Category	Description
0	None
1	barely perceptible, but clearly regular pattern (preventive grinding < 0.5).
2	clear, distinct individual cracks - but no pitting at tip (maintenance, depth < 1.0 mm)
3	clear cracking, pits up to 4 mm diam (corrective grinding 1.0-2.5 mm deep)
4	pitting greater than 4mm < 10 mm (preventive gradual, up to 3.5 mm deep)
5	isolated pitting/shelling/spalling > 10, diam (up to 5 mm deep)
6	Shelling/spalling: regular pitting, >10mm diam (busted, near impossible to catch up on)
7	Shelling/spalling: any defect > 16 mm diam, >20mm length

Accelerometer Systems

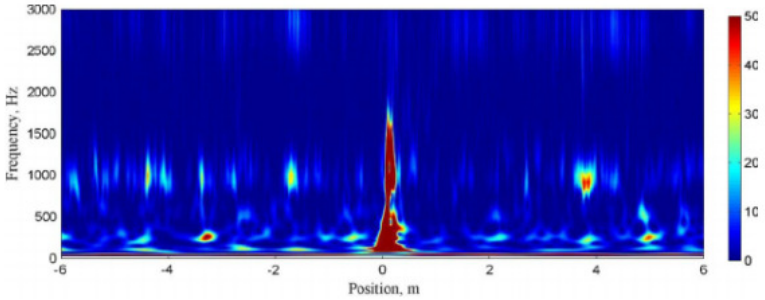




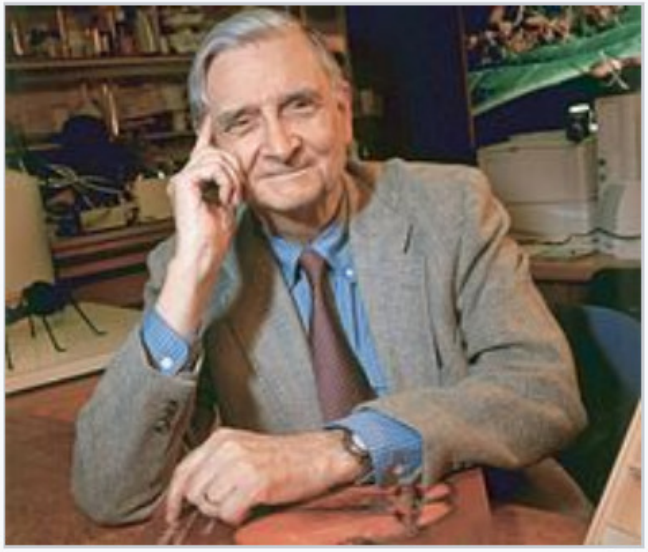
Rail Corrugation signature



https://www.tudelft.nl/kennisvalorisatie/investeren-in-kennis/octrooien/selectie-van-tu-delft-patent-portfolio/detection-method-for-squats/



https://www.researchgate.net/publication/265085881_Automatic_Detection_of_Squats_in_Railway_Infrastructure/figures



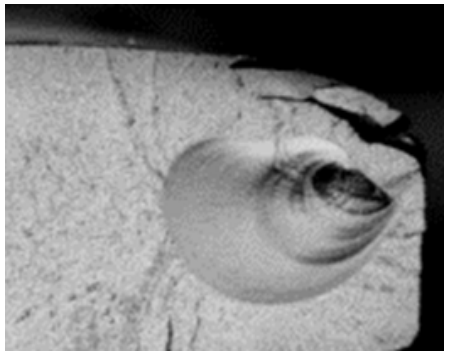
We are drowning in information, while starving for wisdom. The world henceforth will be run by synthesizers, people able to put together the right information at the right time, think critically about it, and make important choices wisely.

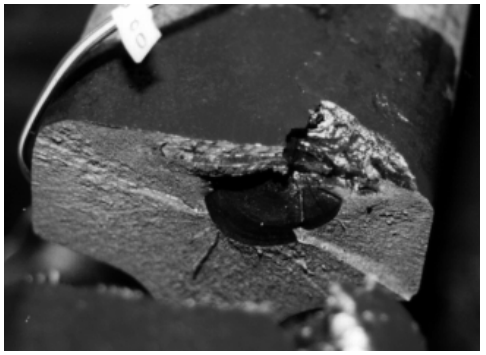
https://en.wikiquote.org/wiki/E._O._Wilson

RCF: What is the Impact?

- Broken rail (pull-apart)
- Broken weld
- Vertical and horizontal split head
- Transverse defect from a deep-seated shell
- Squats
- Crushed Head

- Wheel shelling
- Broken wheel
- Out-of-round wheel





FRA statistics: 2013-2023 Class 1

- T207: detail fracture – shelling/head-check
  - 798 accidents, $413M in damage costs
- T220:Transverse/compound fissure
  - 1820 accidents, $349M in damage costs

UNDERSTANDING

Overstressing the steel

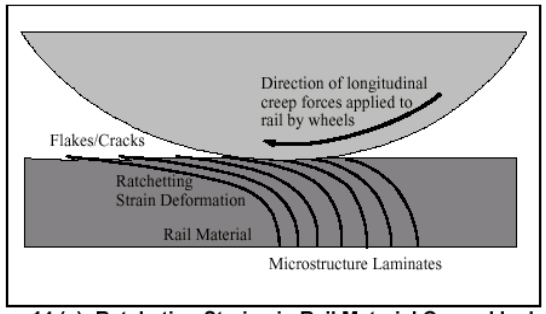
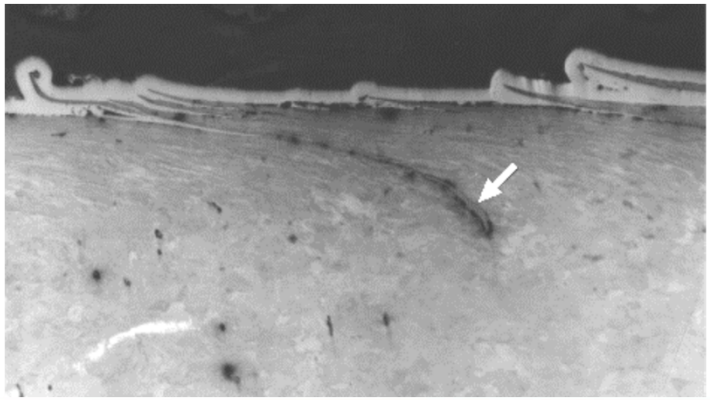
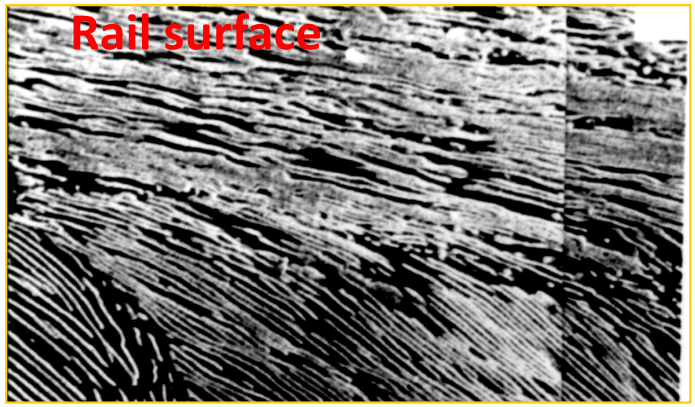
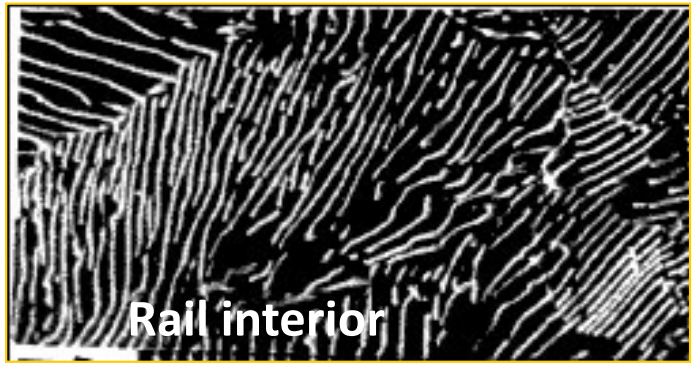


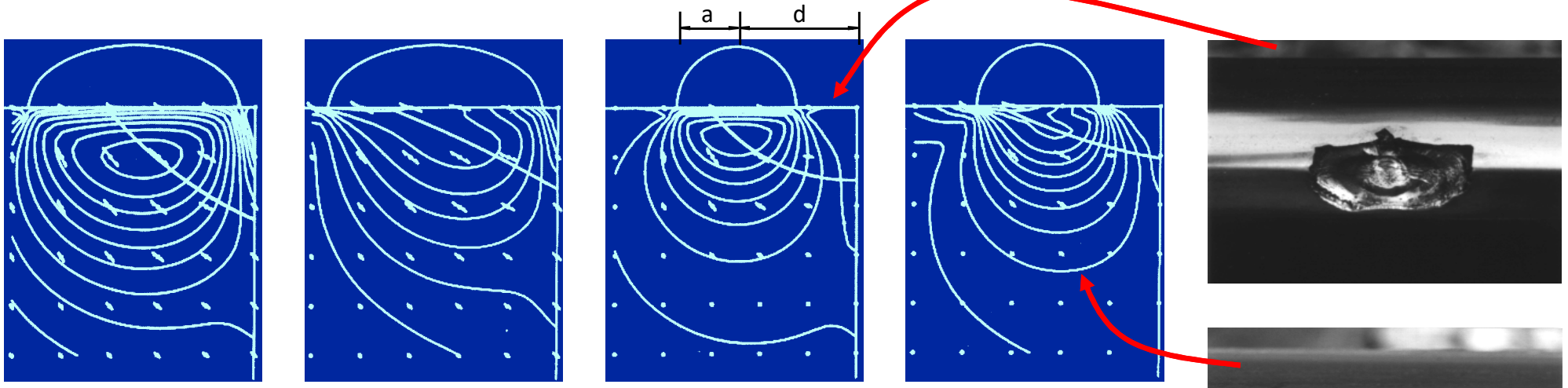
Figure 14.(c): Ratcheting Strains in Rail Material Caused by Large Longitudinal Creep Forces Between Wheel and Rail







Overstressing the gauge corner



d/a=1.14
T/N=0.0

d/a=1.14
T/N=0.4

d/a=2.0
T/N=0.0

d/a=2.0
T/N=0.4

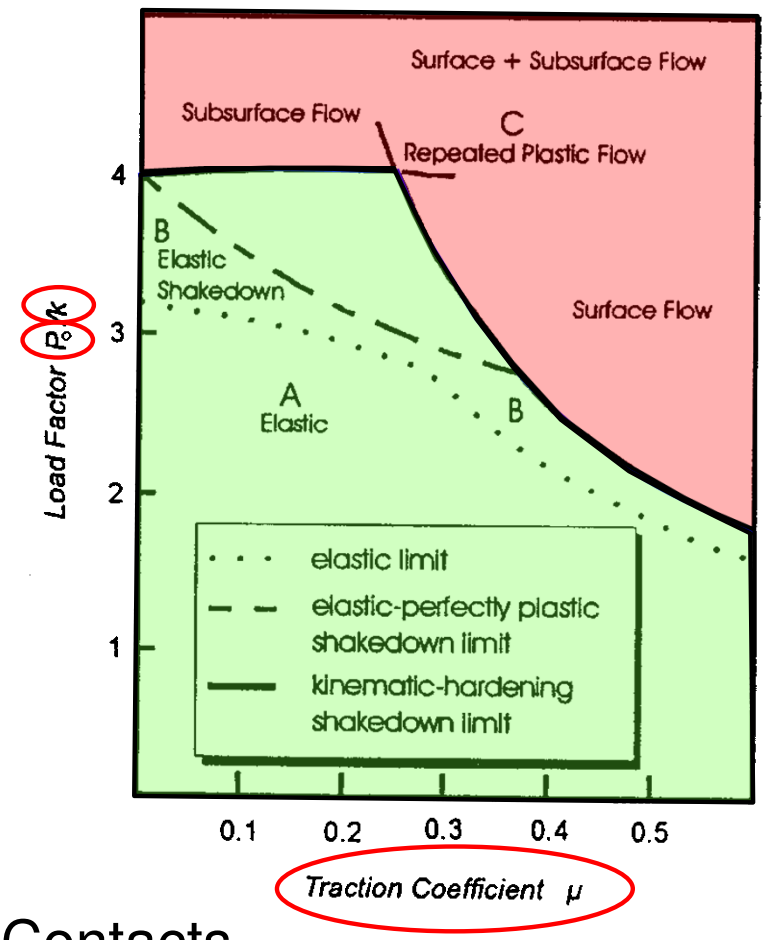
- **Leads to gauge corner collapse**
- **In lubricated track, the DSS's are "cylindrical"**
- **In dry track, the DSS's are "flatter" or "straight"**
- **Collapse is stronger if closer to the edge**

Negative factors for RCF

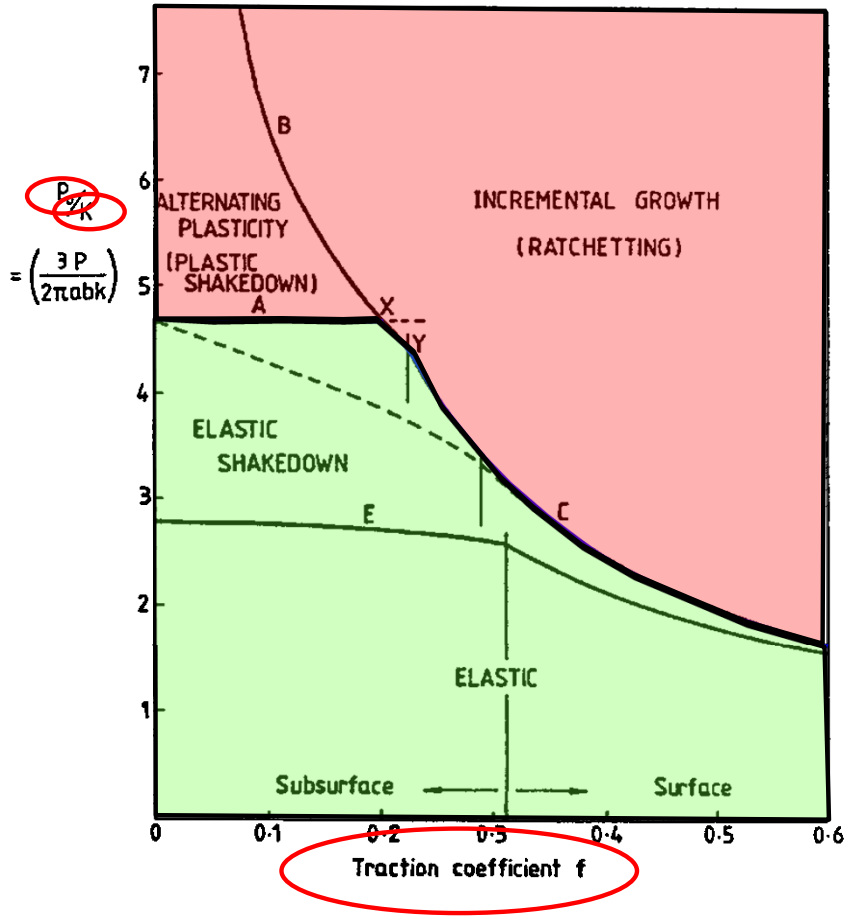
- **Mismatched wheel and rail contact geometry**
- **High dynamic loads**
- **Low material yield strength**
- **Misaligned wheelsets**
- **Track irregularities**
- **Poor lubrication**

- **Increase P_0, worsens steering and hence increases traction**
- **Increases P_0**
- **Reduces k, so increases P_0/k**
- **Worsens steering and hence increases traction**
- **Can increase tractions**
- **Increases tractions in sharper curves**

Shakedown diagram points way forward



Line Contacts



Point Contacts

Role of metallurgy

- Subsurface defects initiate at imperfections in the rail steel
- Harder steels more resistant to plastic flow
- Affects the “Magic Wear Rate” – tradeoff between plastic flow and wear

TREATMENTS

Treatments

- improved wheel profiles
- improved rail profiles
- improved rail grinding and wheel re-truing practices
- friction management
- improved track quality
- improved suspension bogies.
- improved rail and wheel metallurgies

1: Improved Wheel Profiles

- QCM-Heumann wheel: 60% improvement in wheel life
- NCW-ASW (CP 18% increase in wheel life)
- WRISA2 (P12) wheel (UK)

Anti-head check wheel profile

- Network Rail (Railtrack) - broken rail derailment at Hatfield
  - rail replacement, track geometry corrections, rail grinding, rail profiles
  - How about changing the wheel?
  - WRISA commissioned a small effort to develop an “Anti-RCF” wheel
  - Low degree curvatures, 125 mph, high cant deficiency (up to 12 inches)

Dynamic Shakedown Plot

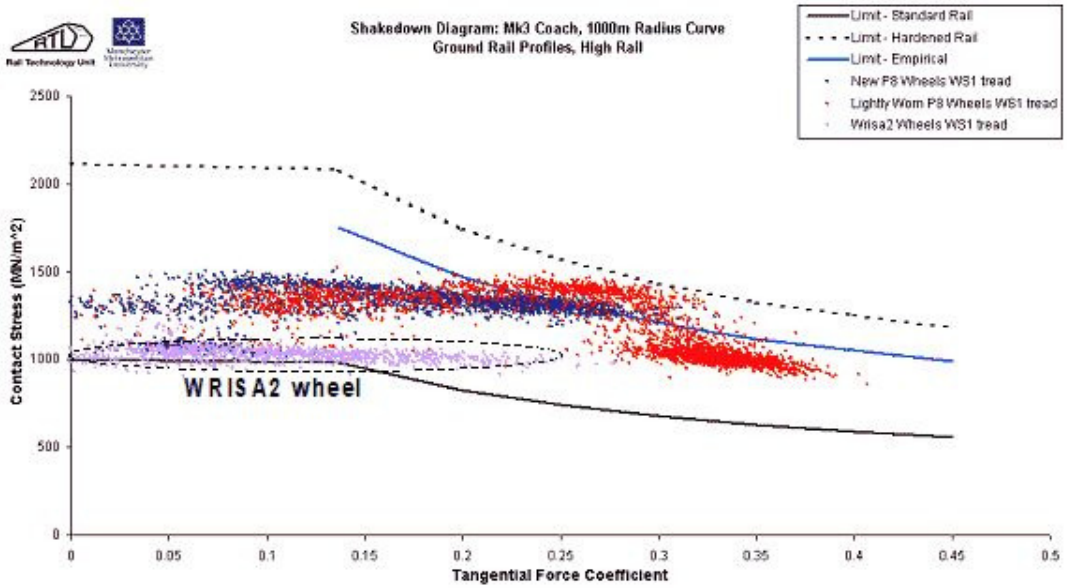
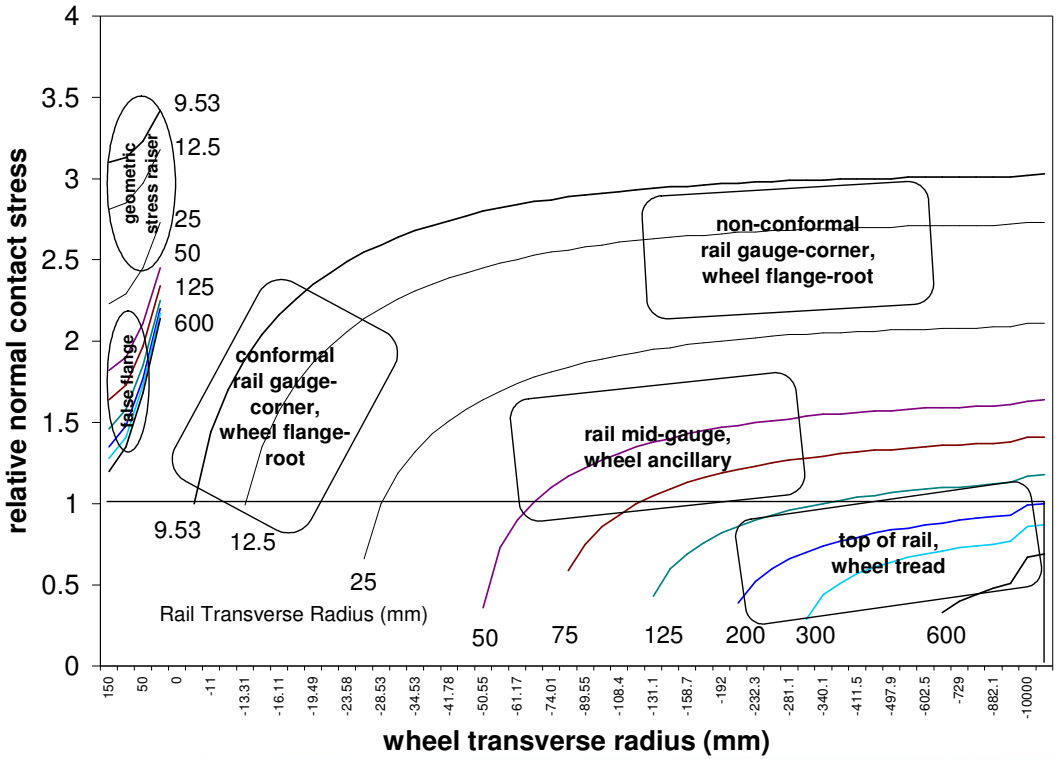
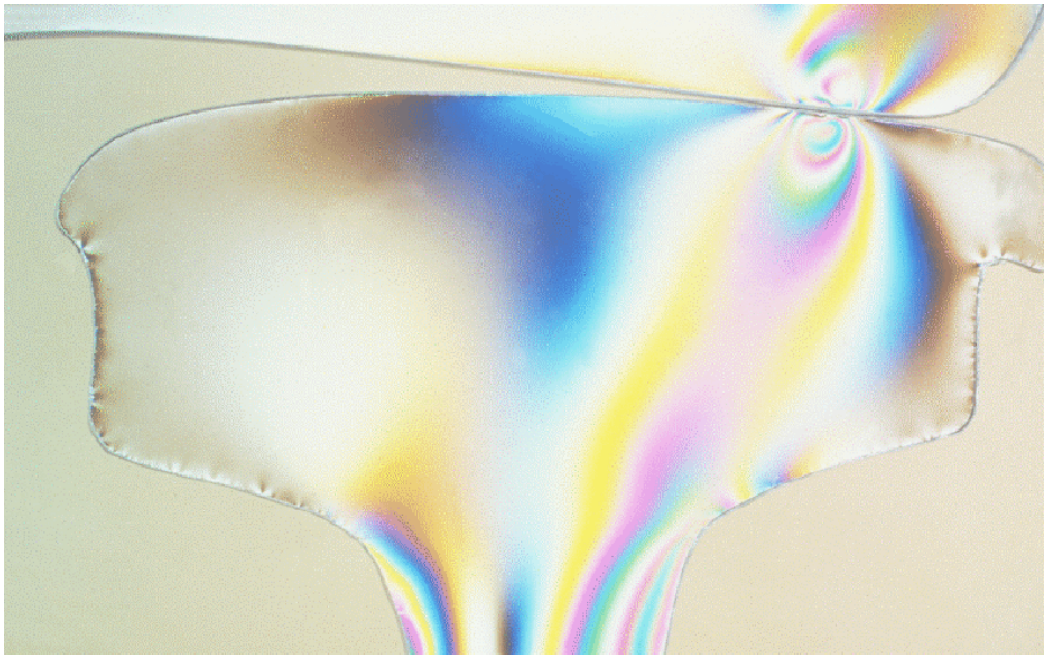


Figure 1: Dynamic shakedown plot summarizes the wheel/rail contact conditions for the new P8, lightly worn P8 and WRISA2 wheel profiles running through a (sharp) 1000m radius curve with ground rail profiles. (shakedown limits are solid line – standard rail, dotted line hardened rail, intermediate solid line is 70% of the difference, an empirical value).

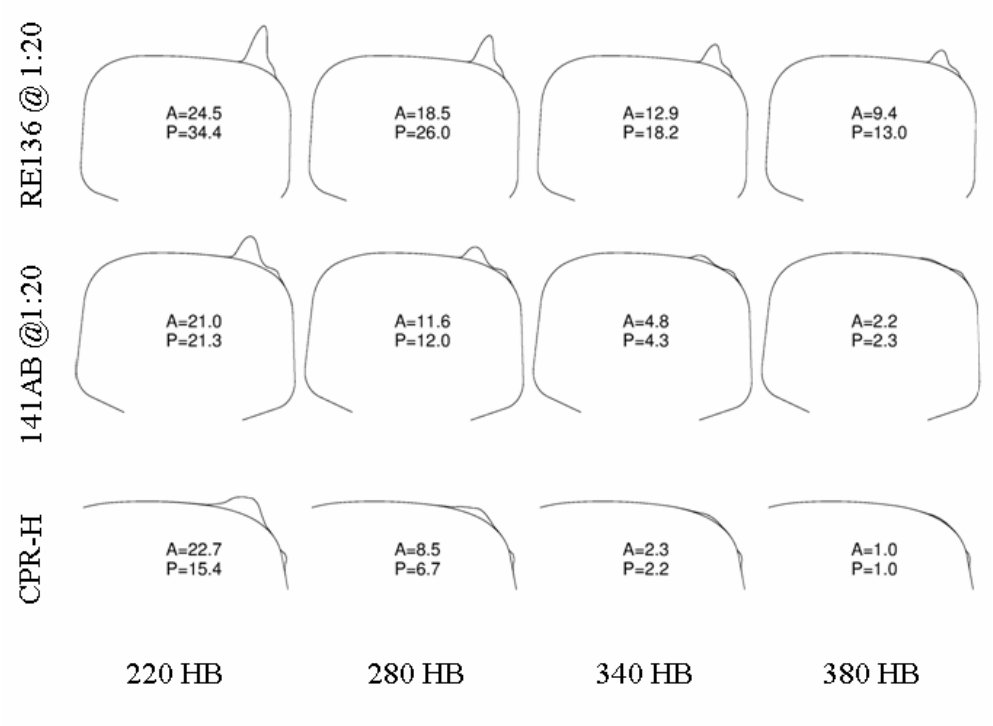
Po: Maximum Normal Contact Stress



Wheel/rail contact



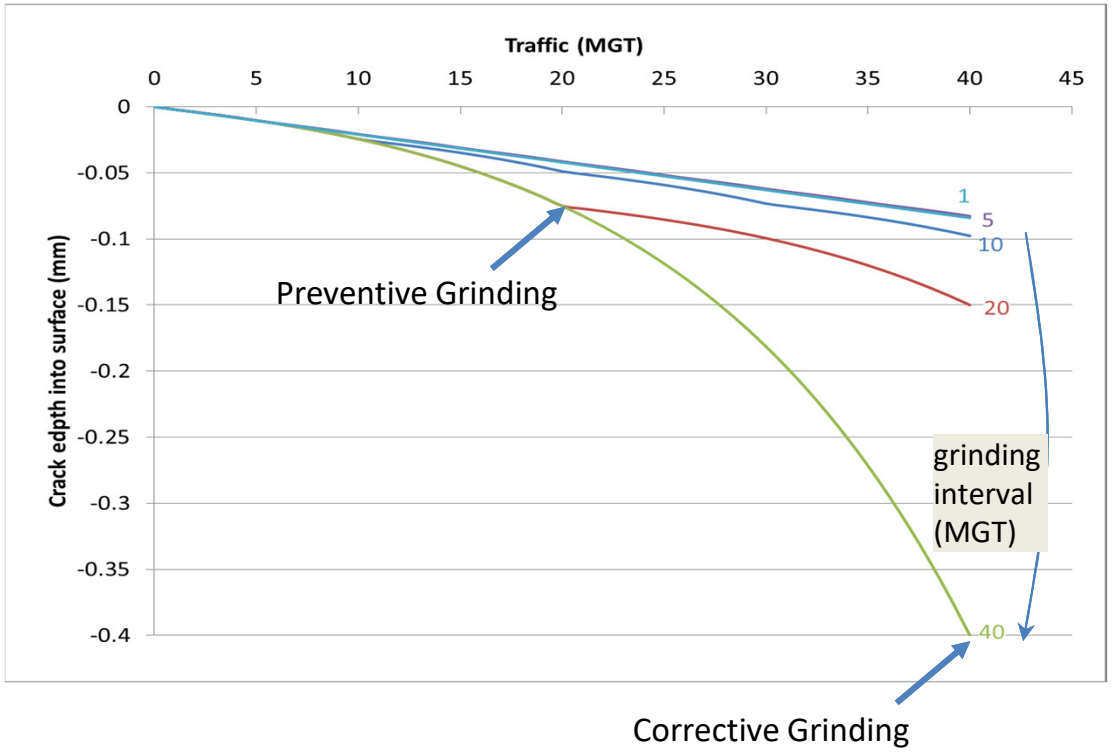
2: Improved Rail Profiles



Synergistic with harder steels

3: Rail Grinding and machining

Crack Growth vs Periodic metal removal



hypothetical exponential crack growth curves

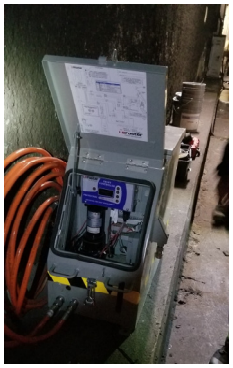
4: (Top-of-the-rail) Friction Management

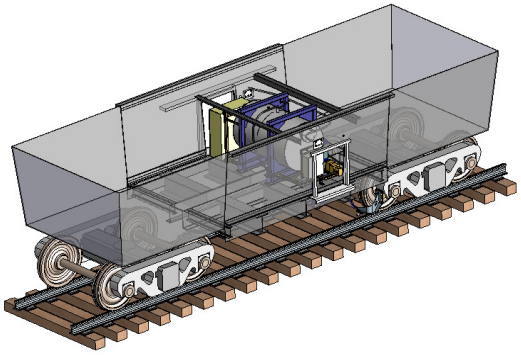
- Limits Surface Traction (shakedown)
- Reduces lateral forces (reduces gauge corner loading)

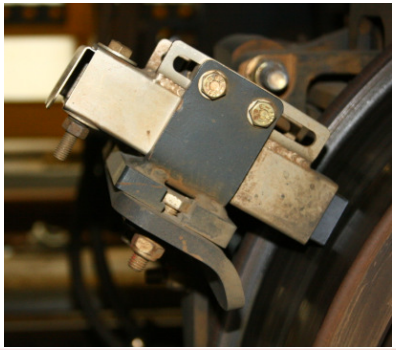
- Synergistic with improved profiles, harder steels

Systems for Managing Friction

- Wayside
  - Electric sensors, pumps
  - Dispenser bars
- Vehicle borne
  - Solid sticks
  - Spray systems
  - Locomotive dispensing
  - Revenue car



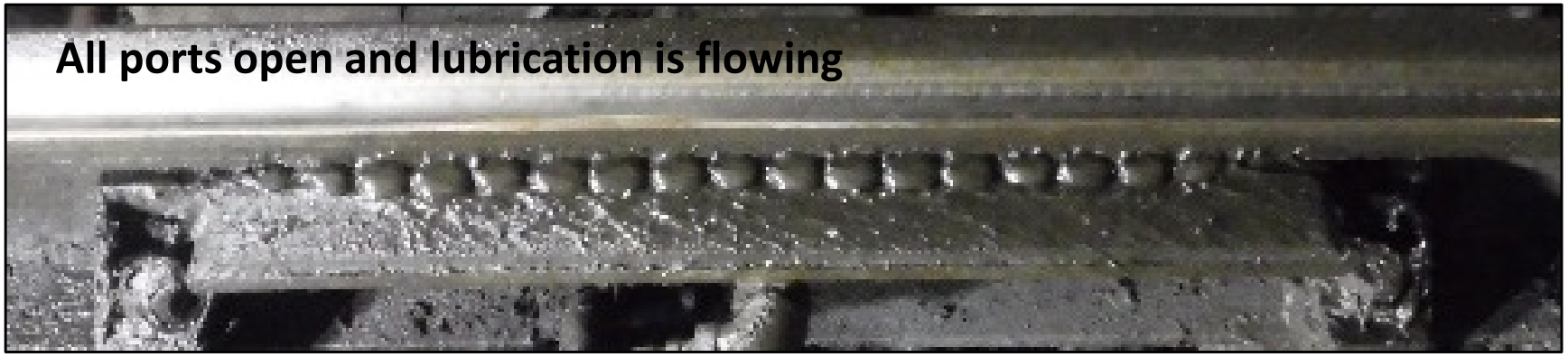




From https://www.lbfoster.com/en/market-segments/rail-technologies/solutions/friction-management/technical-support

http://evolution.skf.com/wheel-flange-lubrication-for-railway-systems-3/

Lubrication



Lubrication

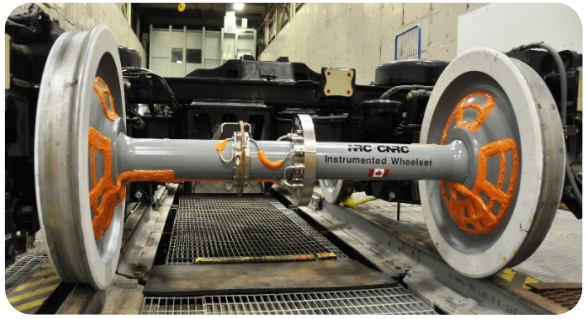
- Wayside Lubricators: criteria for a successful wayside implementation
  - Placement on track (tangent ahead of curve)
  - Bar designs (length, #ports), positive displacement pumps, minimize cavitation (e.g. stir paddles), remote monitoring
  - Selection of grease : summer versus winter
  - Dealing with difficult areas, e.g. embedded track

(TOR) friction management

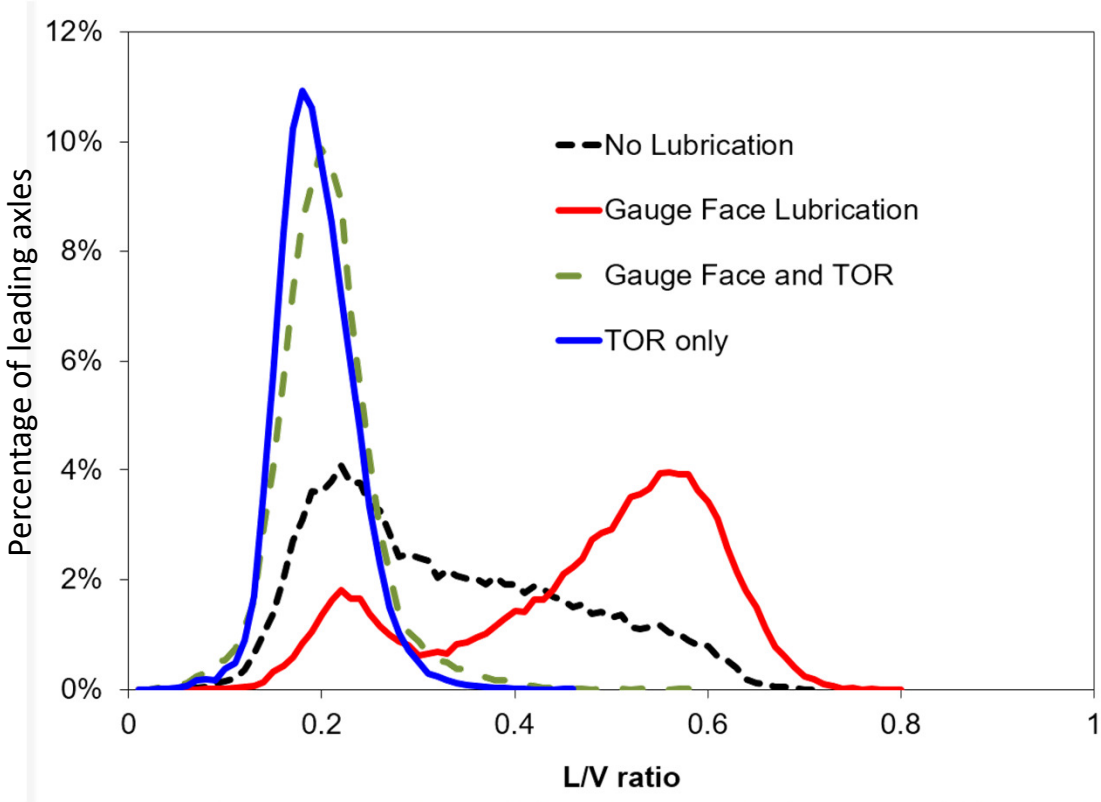
- Product used
  - oil or water based?
  - Solid stick
- Application technique
- Monitoring and maintenance of hardware systems

Friction Measurement

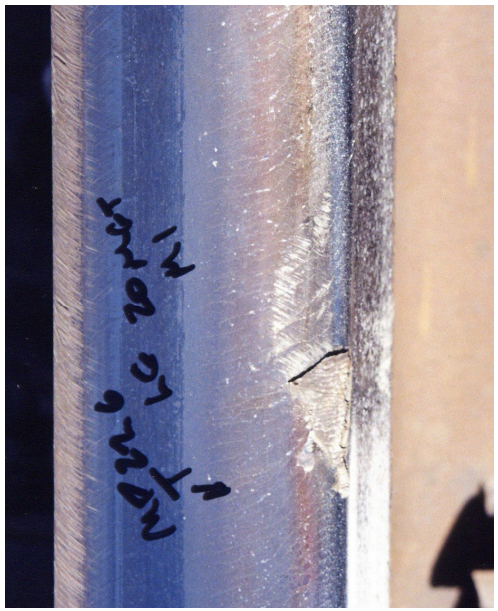
Effectiveness of Friction Management



From P. Sroba et al, Testing of Rail Friction Management on the 377.2 Baltimore Curve, NRC report #54-A62209-T11-2-AUG05



5: Controlling Track Geometry (Errors)

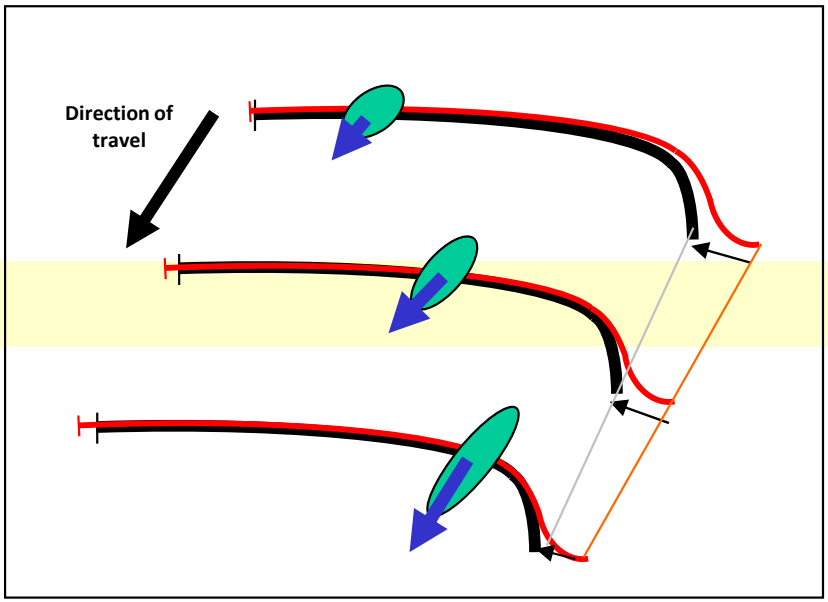


- Track irregularities
- Super-elevation

- Track Gauge
- Plate cut sleepers

Controlling short-wavelength track geometry

- Short-wavelength irregularities
- Plus conformal wheel/rail profiles
  - Give rapid change in contact position
  - Causing instances of very high creep and surface tractions
- Geometry, welds, plate cut, tie problems, joints, etc.



6: Improved Suspension Bogies

- Flexible Suspension – reduces yaw angle
- Reduced wheel shelling on CPR*
  - Steerable trucks 35% greater MTBF compared with conventional coal cars
- M-976 trucks (adopted 2003)

* D. Meyler, P. Sroba, and E. Magel, "Reducing operating costs through improved wheel performance", International Wheelset Congress, Rome, September 2001

7: Rail and Wheel Metallurgy

- K – strength in shear (Shakedown)
- Metallurgical cleanliness
- Alloy steels: nearly doubled life in testing on CN Rail
- Synergistic with wheel/rail profiles that reduce “the stress state”

K – Strength in shear

	Steel	Hardness (Brinnell)	90% HB value	Shear Strength	
				(ksi)	(MPa)
Rail	"Standard"	260-280	278	69.5	480
	"Intermediate"	320-340	338	84.5	583
	"Premium"	340-380	376	94.0	649
	"HE Premium"	380-400	398	99.5	687
Wheel	Class L	197-277	269	67.2	463
	Class A	255-321	314	78.7	542
	Class B	277-341	335	83.8	577
	Class C	321-363	359	89.9	620

8: Inspection and Defect Detection

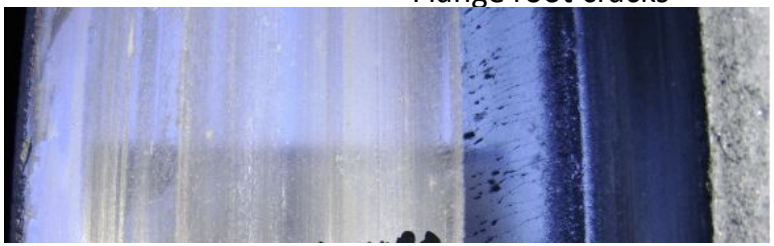
- Rails
  - Regular Ultrasonic testing of rails
    - No test areas often due to surface conditions
  - Vision, machine vision, electromagnetic
- Wheels?

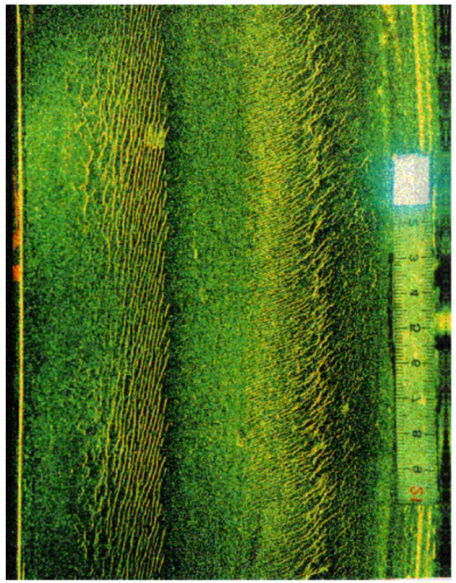
Wheel Surface Condition

Visual, eddy current

Field side cracks

Flange root cracks





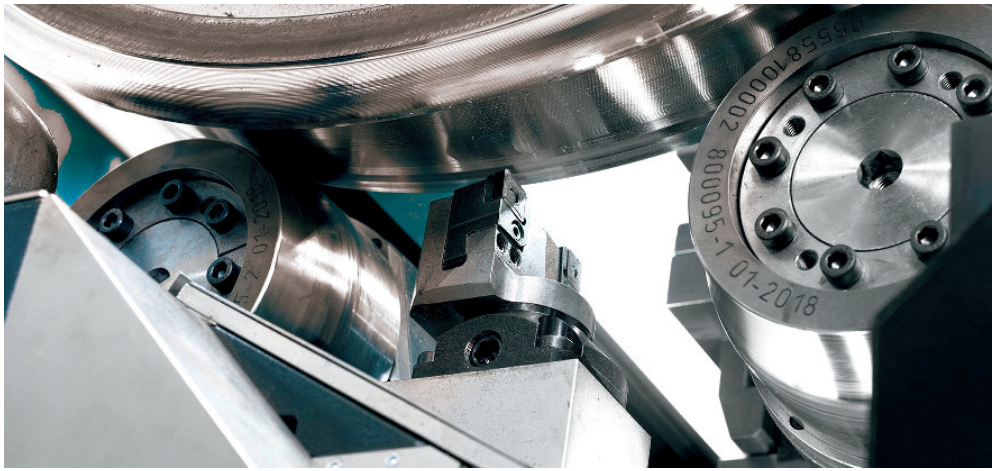
Magnetic fluorescent particle inspection

https://www.railwaygazette.com/news/single-view/view/wheel-surface-crack-measurement-device-could-offer-25-cost-savings.html

WILD rules to remove shelled and OOR wheels

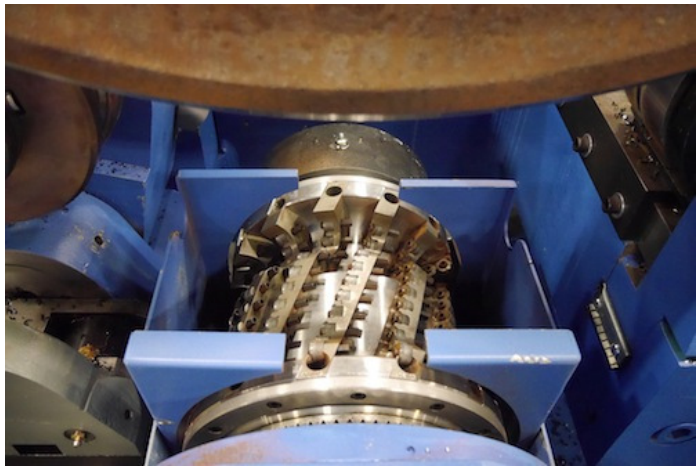
Wheel retruing machines

Lathe



https://railways.danobatgroup.com/en/underfloor-wheel-lathe

Milling



https://smtgroup.com/en/railway-wheel-shop-equipment/underfloor-technology/underfloor-wheel-truing-machine-stanray

Regular inspection and good record keeping

… maintainers who kept detailed wheel condition and maintenance records, and actively managed and optimised their maintenance practices, achieved significantly better wheel life than those who did not.

RSSB summary report T963: Improving wheelset life by better understanding the causes of wheel damage, July 2019

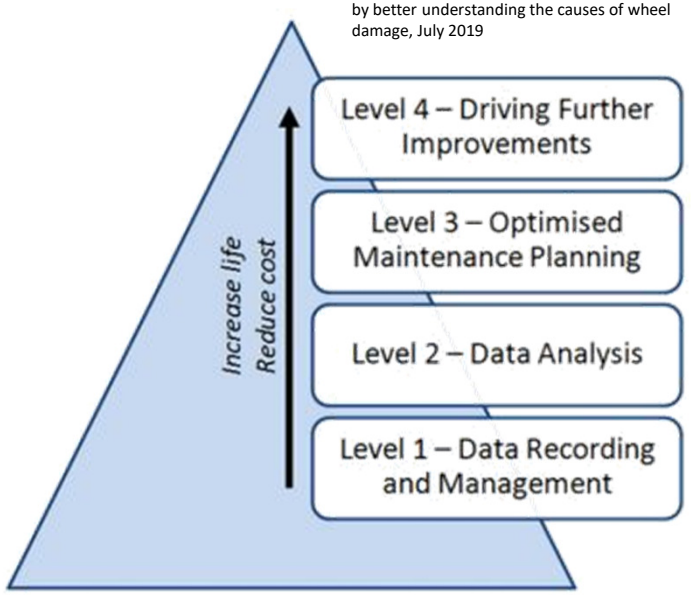


Figure 3 - Management and optimisation of wheelset life

Managing RCF

- Investigation
  - what defects are most prevalent, most expensive, most dangerous?
- Constraint Identification
  - Financial, manpower, co-operation/authority (e.g. engineering vs mechanical)
- Evaluation of Options (grinding, TOR-FM, TG errors, improved steels, …)
  - Cost-benefits analysis (“bang for the buck”)
- Trial and Validation
  - Validate CBA
- Implementation

THANK YOU

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