Understanding Rolling Contact Fatigue: What can be done to lower the risks?

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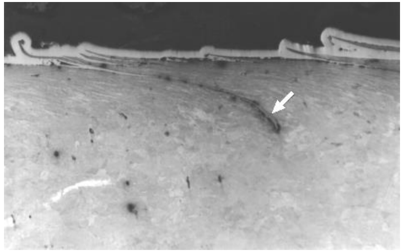
Rolling Contact Fatigue

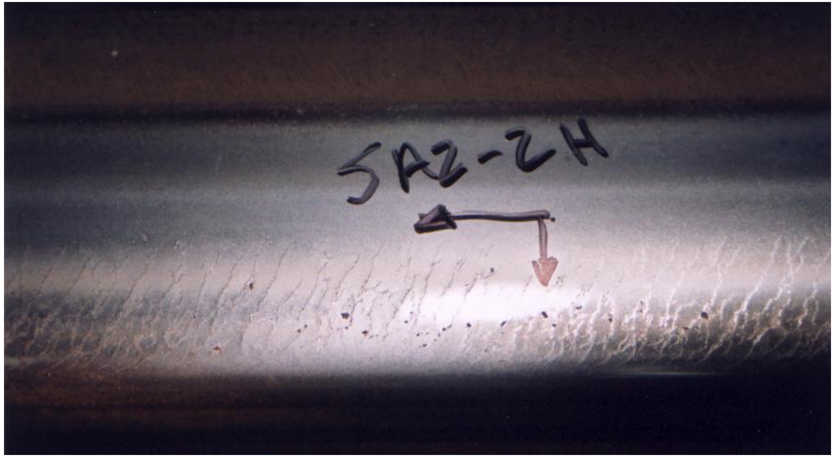
- Rail ≈ 4 million cycles/100 MGT
- Wheel ≈ 33 million cycles/100K km
- High contact stress + friction + slip
  - plastic deformation - ratcheting
  - work/strain hardening
  - fracture → **Surface crack**



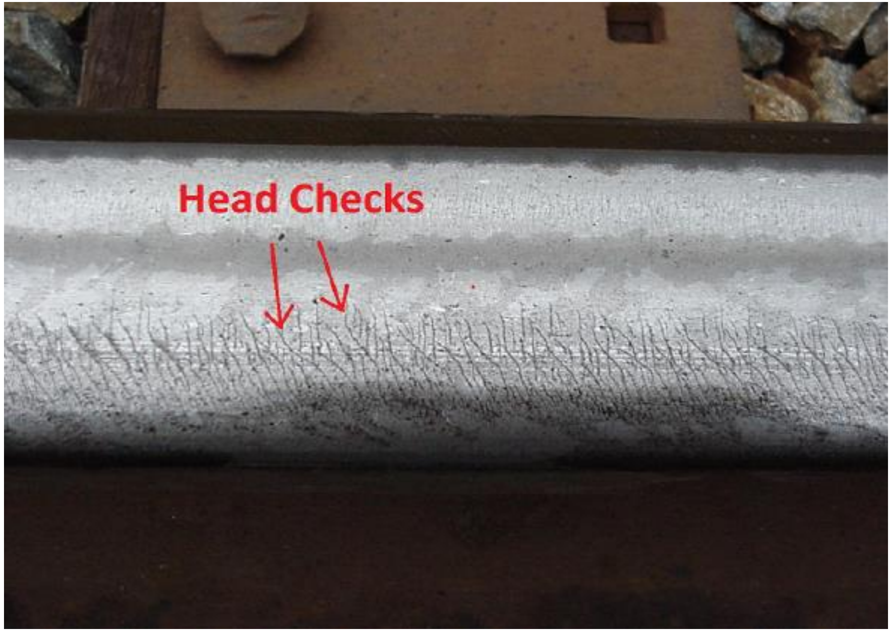
Outline

- RCF – a pictorial review
- Modeling
- Stress state
- Risk and risk management
- Looking to the future

Head Checking



Source DOT RSAC presentation March 2013)



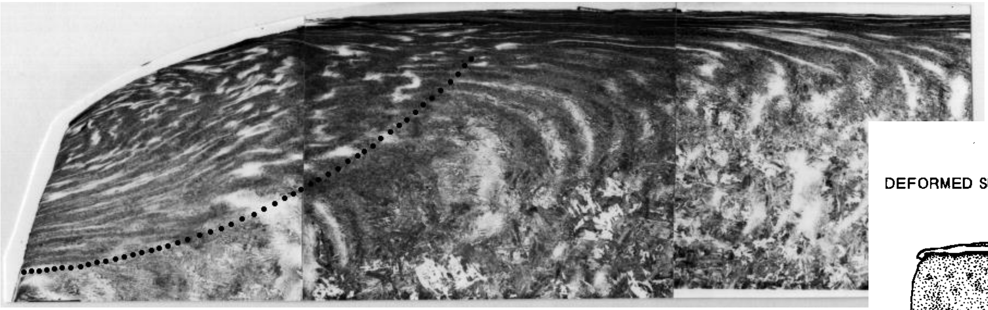
Pitting and shelling

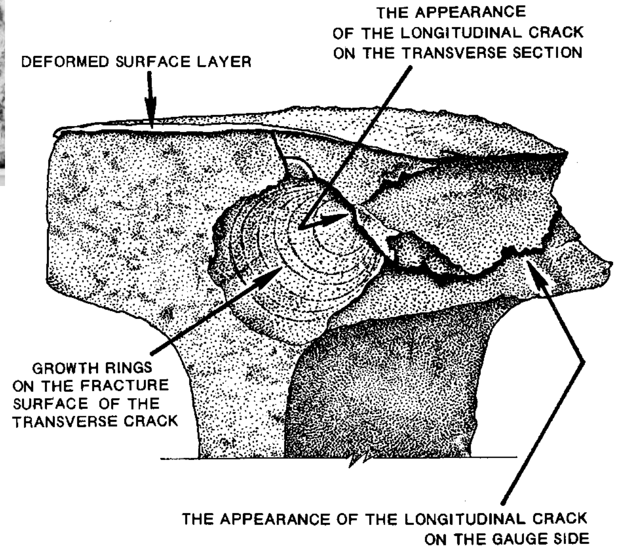
Dished low rails

RCF Corrugation

- High dynamic forces
  - degrades ballast
  - noise
- Heavy unit trains
- Consistent speed
- Discrete irregularities
  - welds, joints, crossings
- P2 resonance

Transverse defect





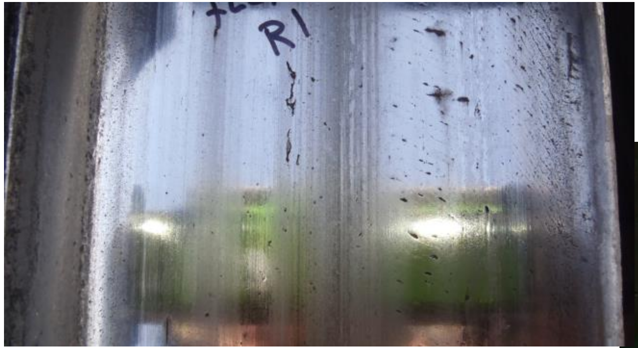
Need to grind regularly so that stress peak continually moves through the rail.

Deep seated shells

Figure 1a. DSS defect originating 6 mm below the gauge corner was detected by the ultrasonic car.

Figure 1b. DSS defect that has turned into a transverse defect and broken the rail under traffic.

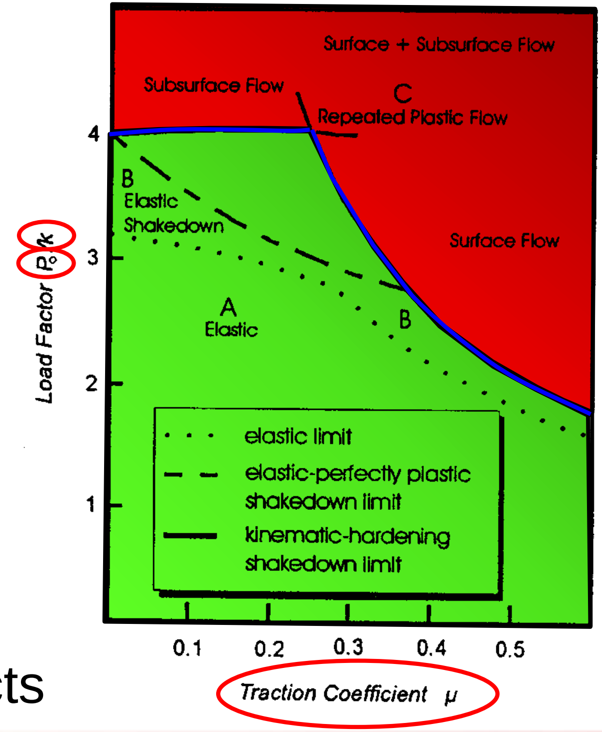
Wheel surface damage equivalents



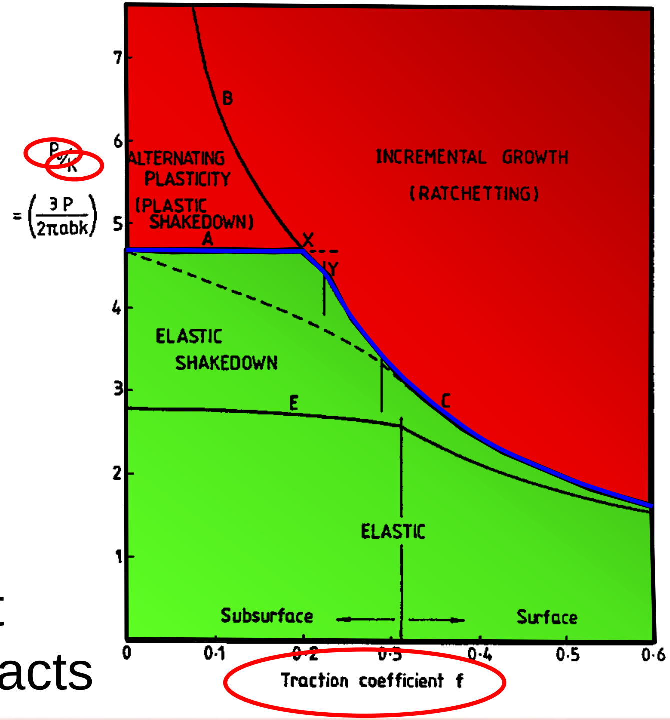
RCF: Formation

1. Contact Mechanics
2. Friction
3. Materials
4. Dynamics

Shakedown



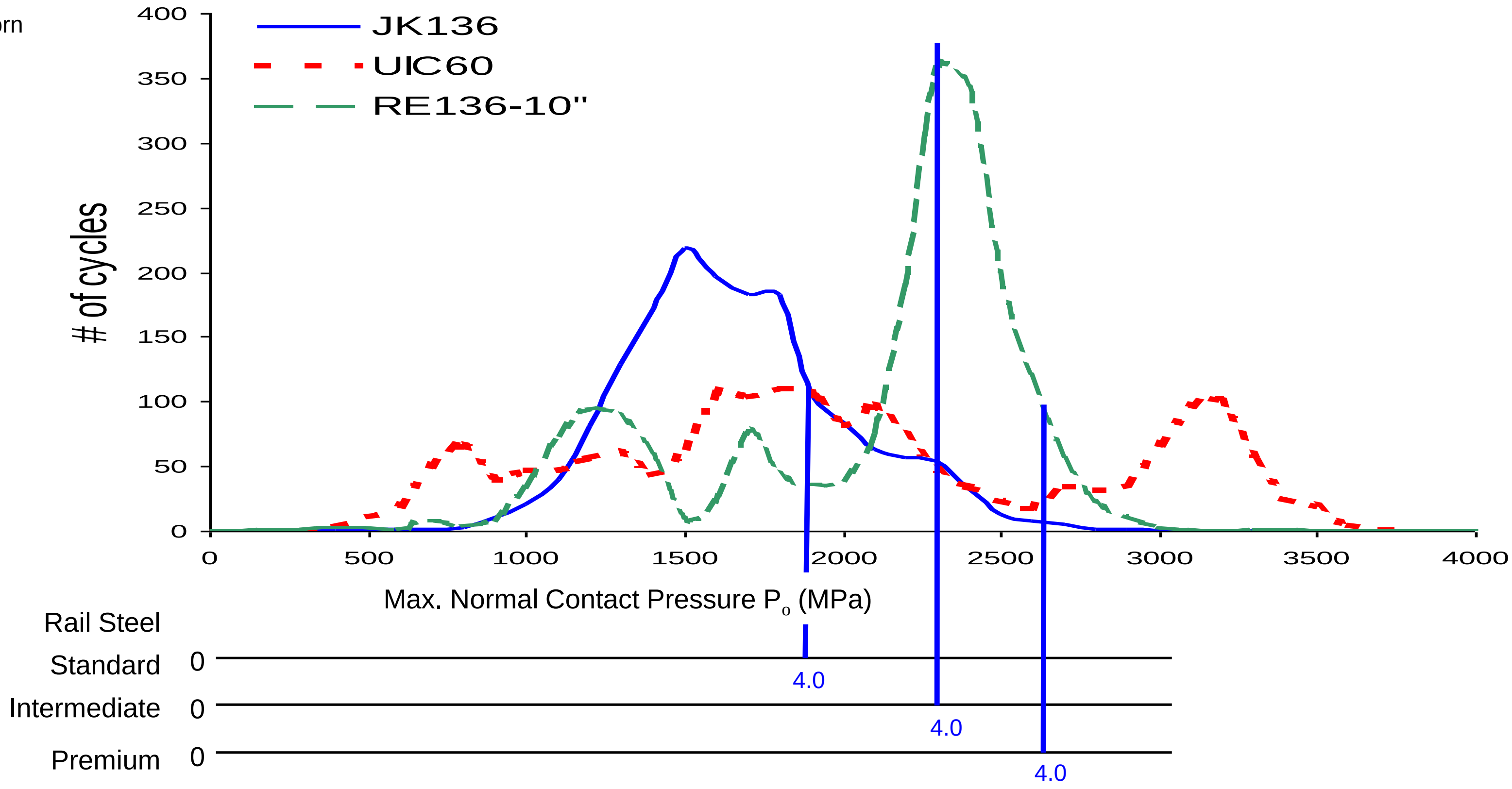
Line Contacts



Point Contacts

North American
Grain and Coal
2053 new and worn
wheels

Sharp curve,
high rail,
leading and
trailing axles



Dynamic Shakedown Plot

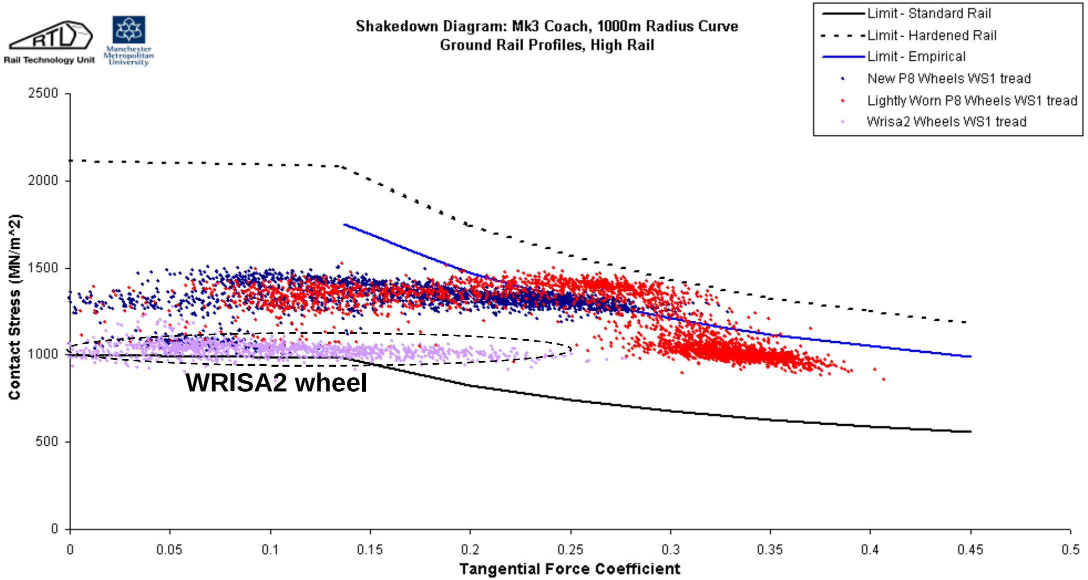
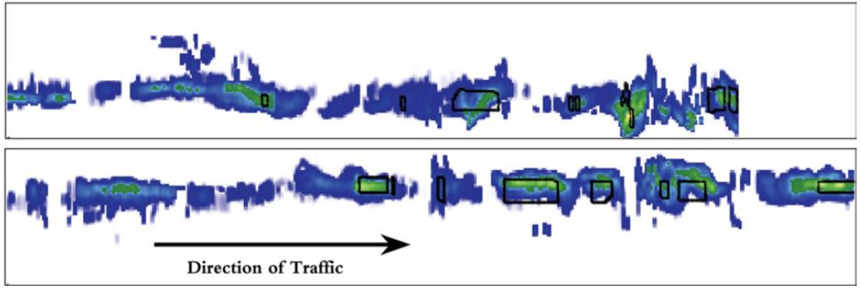
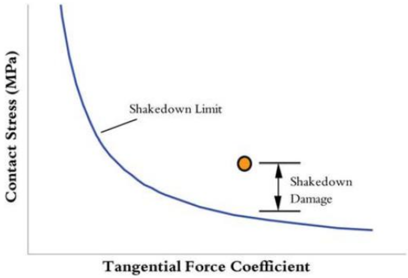


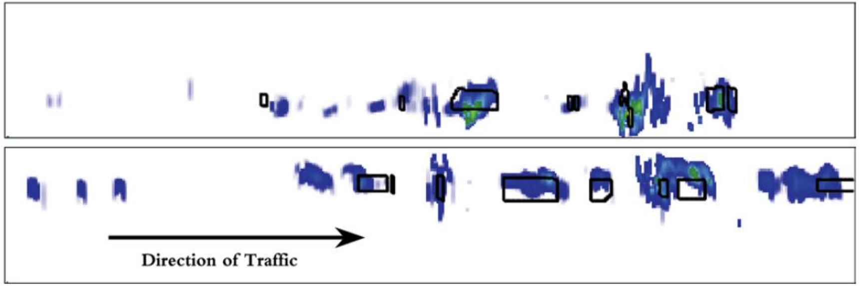
Figure 1: Dynamic shakedown plot summarizes the wheel/rail contact conditions for the new P8, lightly worn P8 and WRISA2 wheel profiles running through a (sharp) 1000m radius curve with ground rail profiles. (shakedown limits are solid line – standard rail, dotted line hardened rail, intermediate solid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

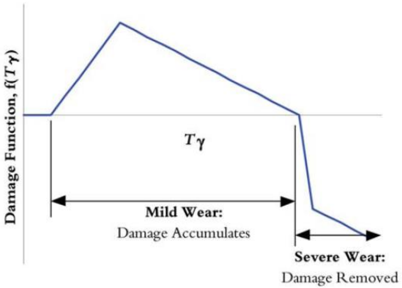
RCF Modeling and Prediction

Ruscombe S&C





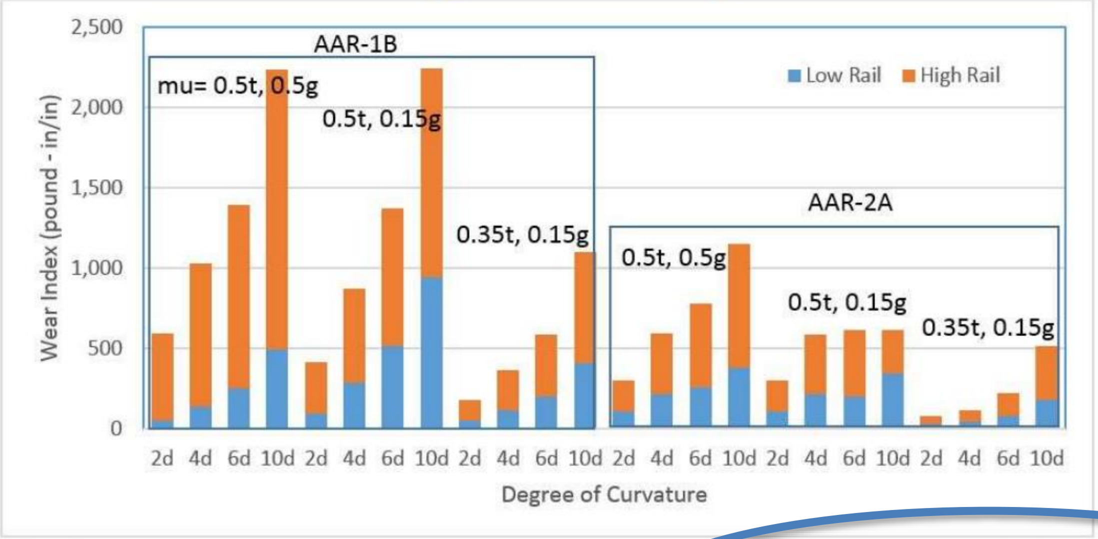




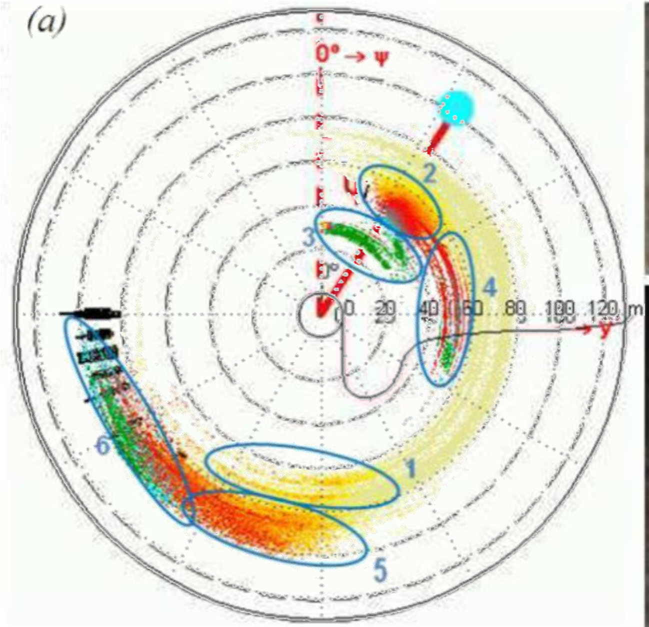
Burstow M., Whole Life Rail Model application and development for RSSB (T115) - continued development of an RCF damage parameter, report AEATR-ES-2004-880 Issue 2.

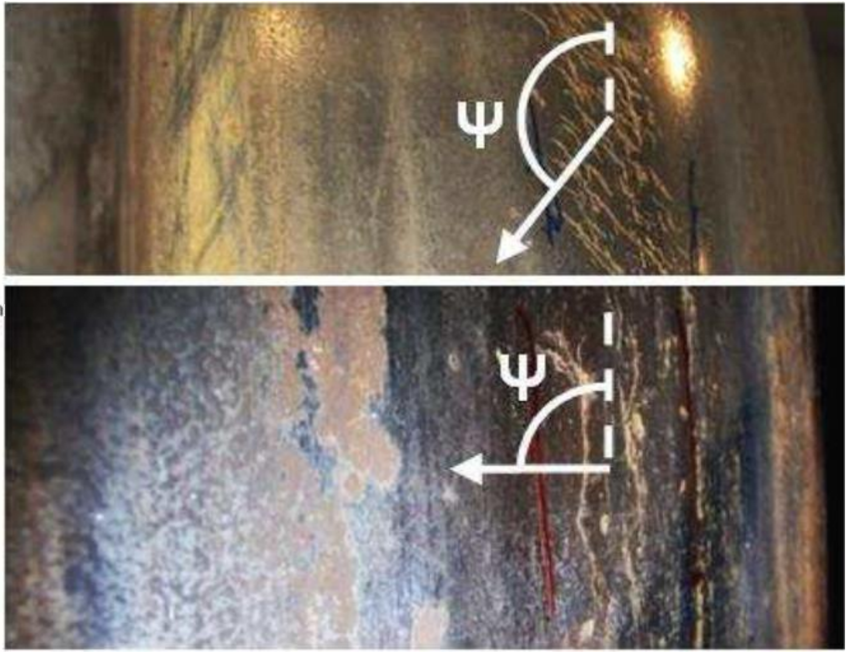
NUCARS® Simulation of AAR-2A

- **Reduced wear and rolling contact fatigue**



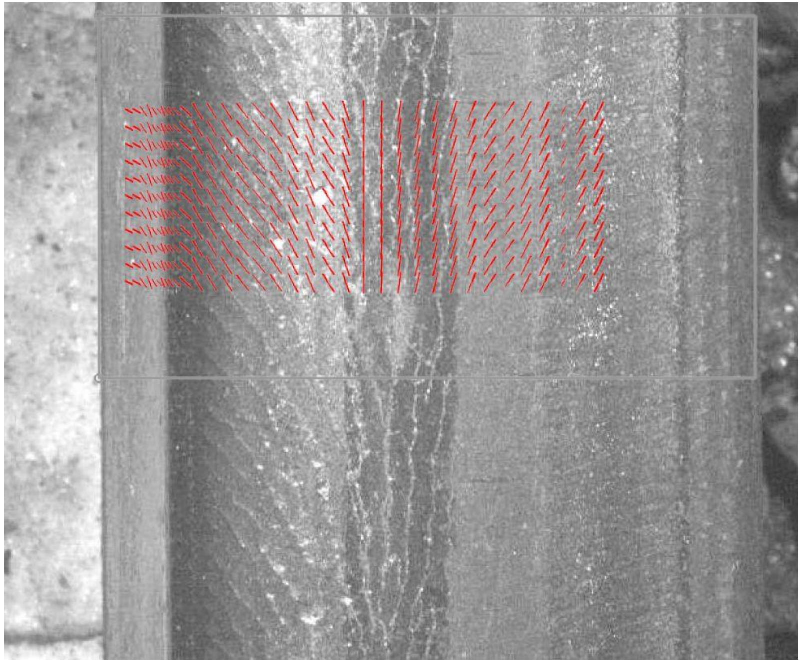
Polar plot of RCF damage

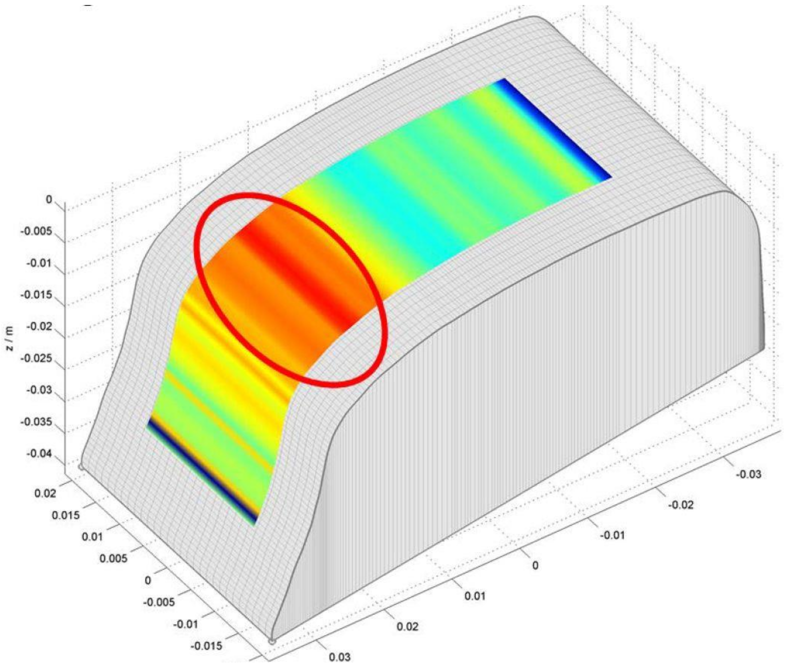




Molyneux-Berry P. and Bevan A., Wheel surface damage: relating the position and angle of forces to the observed damage patterns, *Vehicle System Dynamics*, Vol. 50.1 (2012)

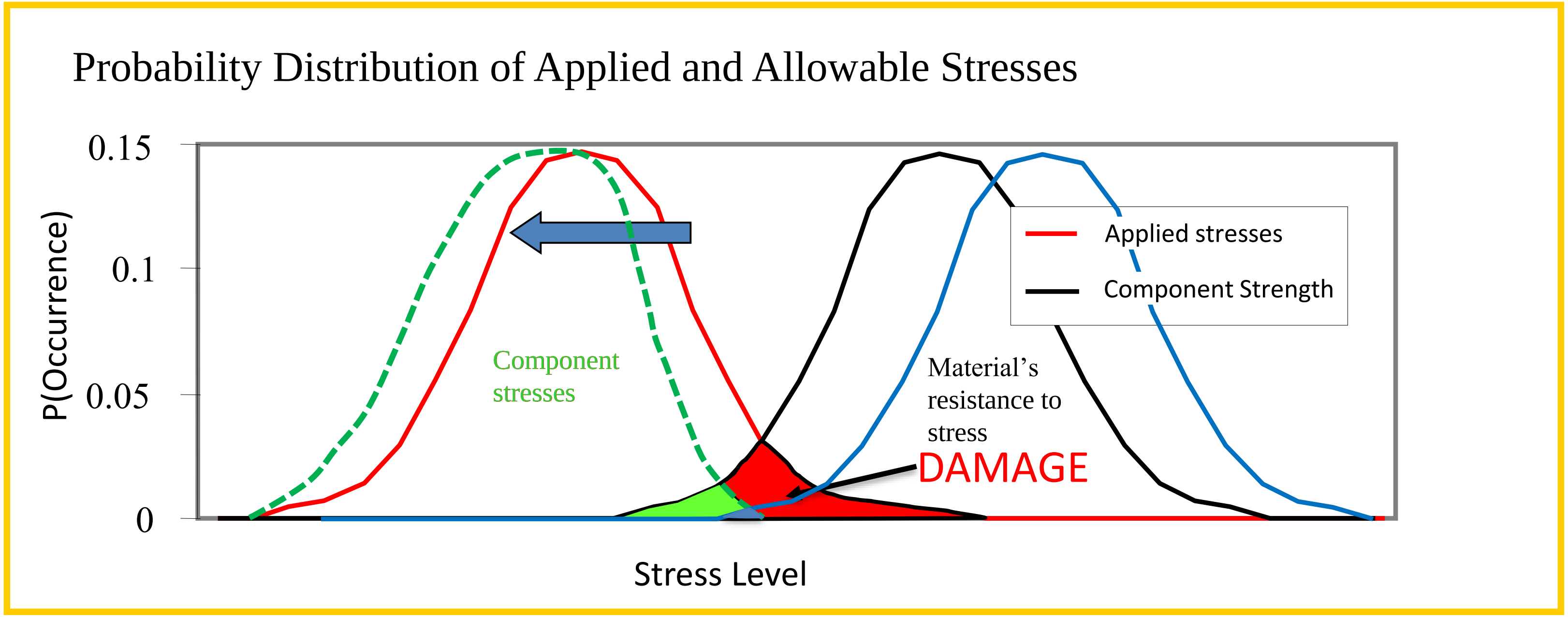
RCF modeling – Rail surface cracking





Trummer G., Marte C., Dietmaier P., Sommitsch C. and Six K., Modeling surface rolling contact fatigue crack initiation taking severe plastic shear deformation into account, *Wear*, Vol. 352 (2016), 136-145

Stress vs Strength



Stress vs strength (cont'd)

Reduce stress

- Friction management
- Optimized wheel and rail profiles
  - regularly maintained
- Minimize track geometry errors/perturbations
- "Track friendly" suspensions

Increase "strength"

- Friction management
- Improve materials
- Remove fatigued/damaged layer (e.g. grinding)
- Improve track geometry (inc. optimize super-elevation)

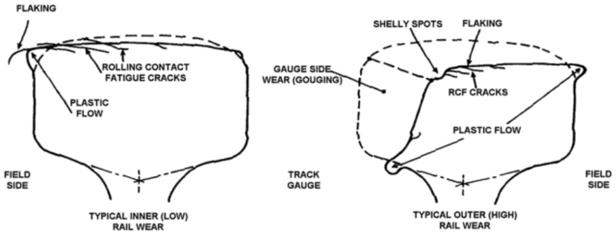
Risk – and managing it

RCF origins of risk

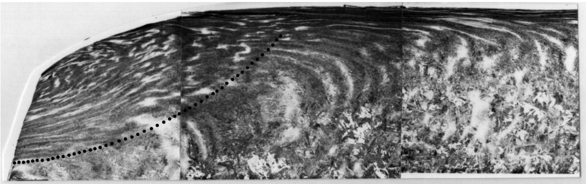
1. Root cause in many broken rail derailments.
   – top eight cause of derailments in EU, USA and Russia
   – USA: RCF is the cause of roughly 10% of <u>all</u> FRA reported derailments.
2. Compromise the effectiveness of internal rail flaw detection systems.

RCF - root cause in many broken rail derailments

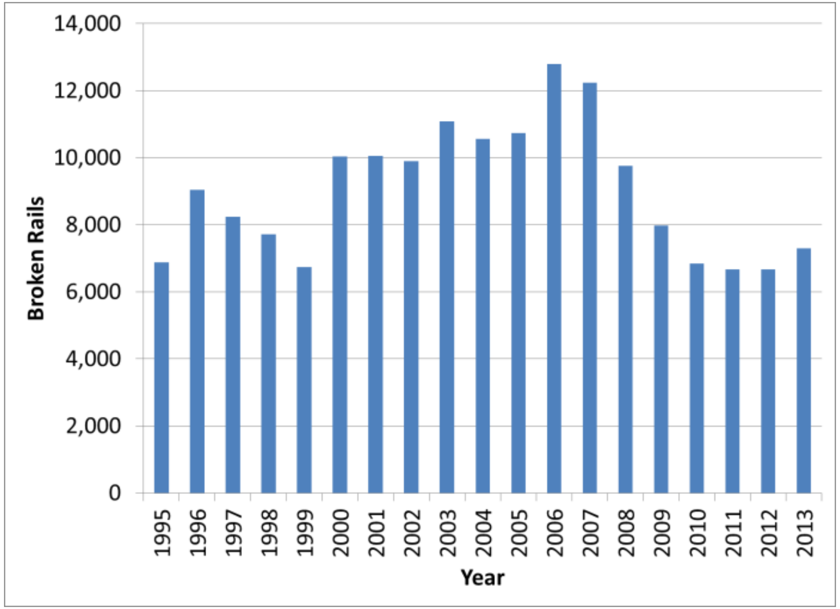
- *transverse defects*
  - *squats – few derailments, large $$$*
    - *Japan:* 50% of defects, 20% of rail removals
  - *head checking*



  - *gauge corner collapse*



Broken Rails – North America



Number of broken rails per year from 1995-2013 (inclusive) for the seven largest US Heavy Haul railroads.

Dave Sheperd, Eric E. Magel and Bob Harris,
“**The Impact of RCF and Wear on Rail Safety**
AREMA annual conference 2016

FRA statistics: RCF caused Main Track Derailments

* For T207: Detail fracture and T220: Transverse/compound fissure

	1995 - 2002	2003 - 2010	2011 - 2018
Total Derailments*	374	424	184
Total costs* ($M)	127.4	210.2	109.2
Cost per derailment* ($M)	0.34	0.50	0.59
Derailments / BGTM	17.6	17.3	7.3

Ellicott City, Maryland 20AUG12

- Coal Train, bridge, 2 trespassers killed
- Several TD’s over 5 metre length
- Largest defect: 24% of the head area
- Last UT inspection: <1.5MGT prior

Others:

- New Brighton, Pennsylvania (October 20, 2006)
- Columbus, Ohio (July 11, 2012)
- Gainford, Alberta Canada (19 October 2013)

Treatments for RCF caused broken rails and derailments

- Minimizing RCF through
  - Optimized W/R profiles
  - Friction management
  - Improved metallurgies
  - Improved suspensions
  - Correcting track alignment errors
  - Rail grinding

Successful grinding program

- Good technology
  - Stable platform, high horsepower, fire-suppression, on-line profile measurement, QA
- Good planning
  - Incorporates current rail condition, defects, etc.
- Good Strategy

Rail grinding strategy

Corrective (e.g. >60 MGT)

- Less frequent
- More metal removed each cycle
- Less track covered
- Rail profiles deteriorate
- Surface damage often significant

Preventive (e.g. 20 MGT)

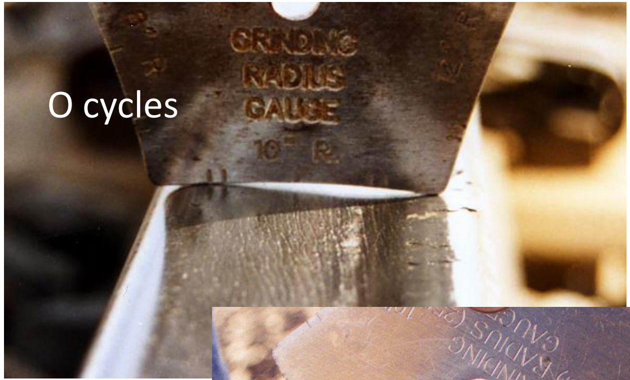
- More frequent
- Less metal removed each cycle
- Covers the system quicker, maybe several times / year
- Rail maintained so always in good shape

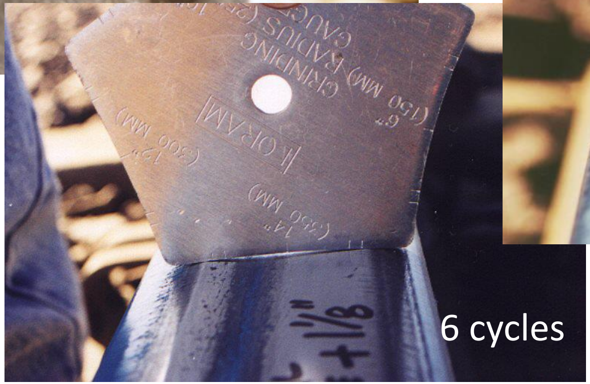
Preventive Gradual (e.g. 20 MGT)

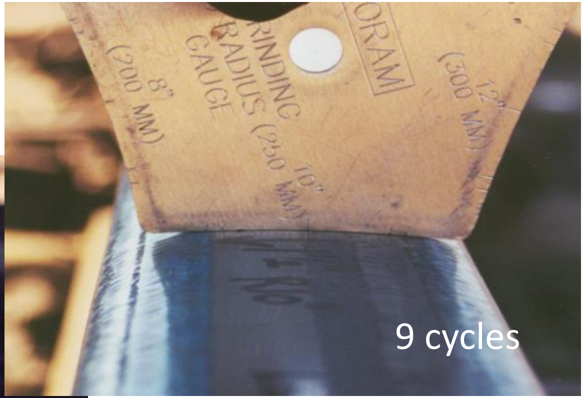
- More passes than preventive to catch up on poor rail
- Almost same interval and cycles as preventive
- Rail shape improved quickly to reduce stress, then catch up on damage

“Catching up” on low rails

Preventive Gradual







Improved inspection/detection

Alternative positions and directions

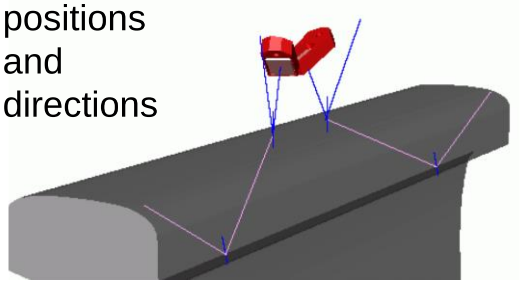
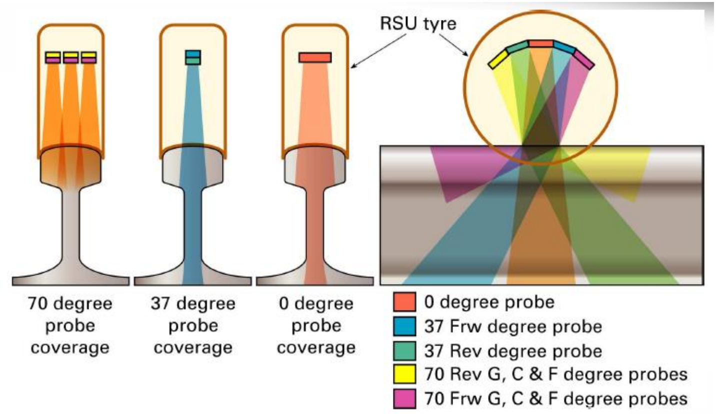


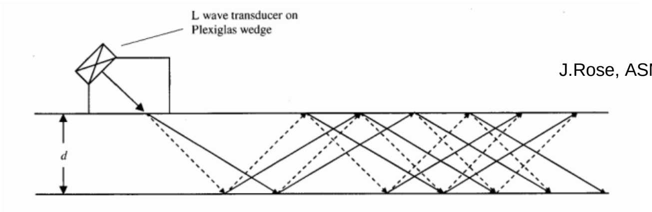
Image courtesy of S. Broomhead of Sperryrail



Multiple ultrasonic probes

J. Richards and R. Clark, Aston University July 2007 Industrial CASE awards

Combining technologies: acoustic + induction + ??

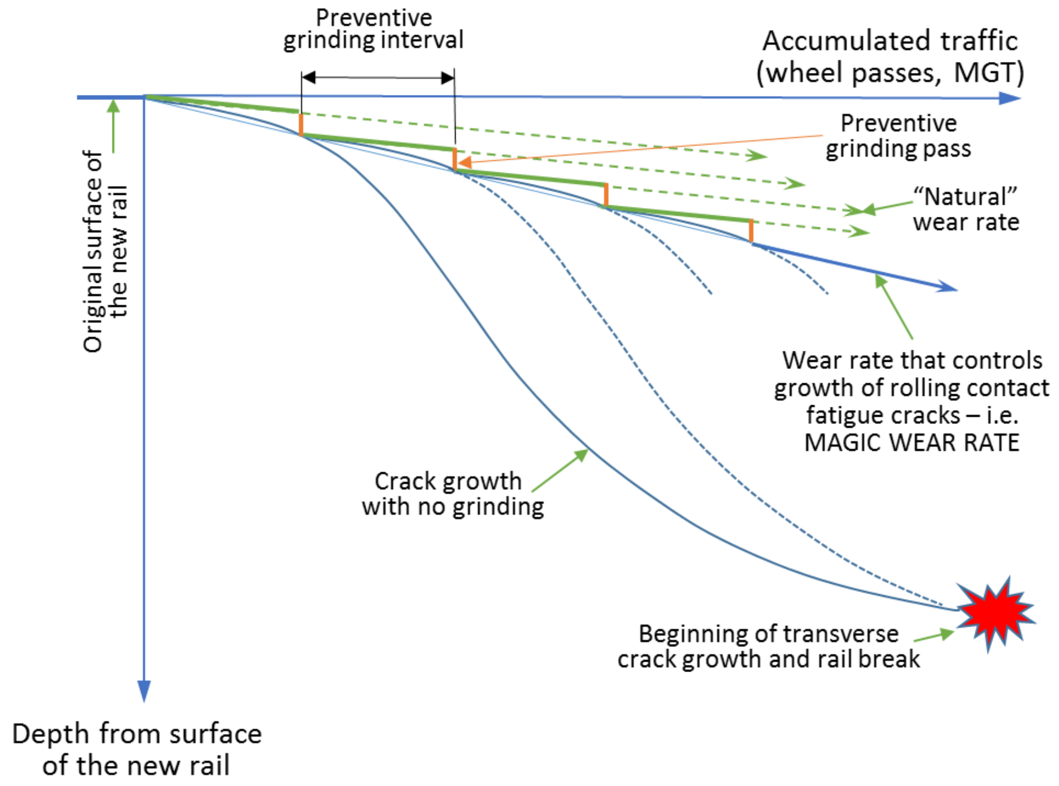


J.Rose, ASME, 2002

Longitudinal guided waves?

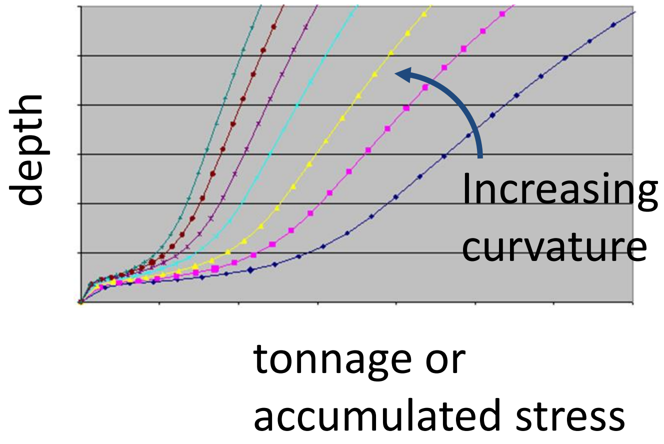
Managing RCF
Into the Future?

Preventive Rail Grinding



A family of crack growth curves

- probably for different
  - rail steels
  - territories
  - traffic types (e.g. passenger, transit, freight)
  - friction regimes



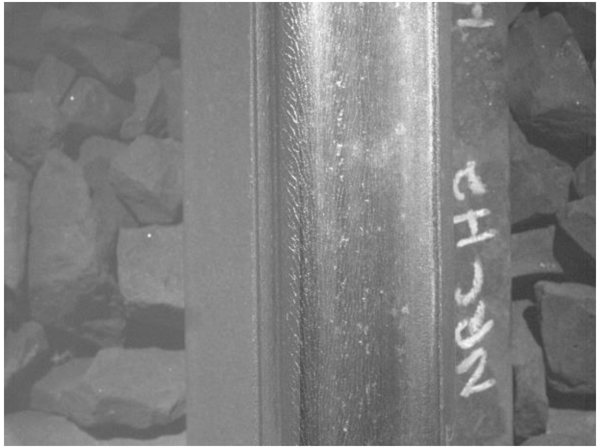
Electromagnetic Walking Sticks

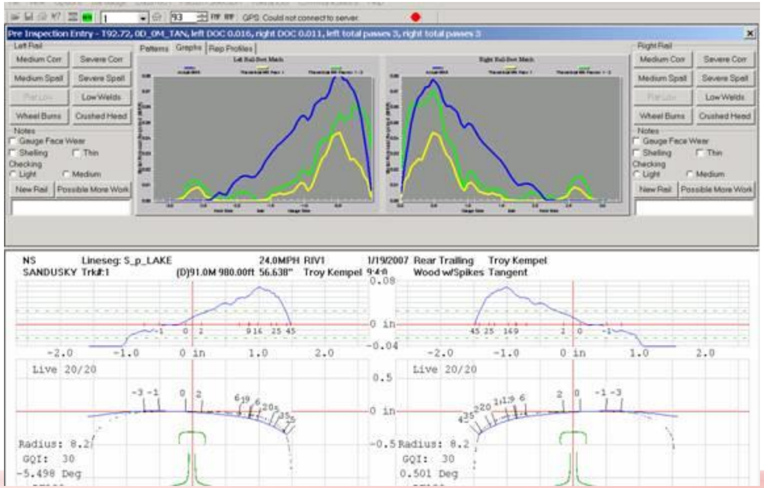
Rohmann Draisine
(eddy current)

Sperry walking stick
(eddy current)

NEWT Lizard
(ACFM)

MRX RSCM
(magnetic flux)




GPS: Could not connect to server.
Left Rail
Right Rail
NS
SANDUSKY
Lineseg: S_p_LAKE
Trk#:1
24.0MPH RIV1
1/19/2007 Rear Trailing
Troy Kempel
Wood w/Spikes Tangent
Live 20/20

Prevention (and Treatment)

- Reduce the stress
  - optimized and managed profiles
  - managed friction (control T/N)
  - minimized track geometry errors
  - advanced suspensions
- Increase the strength
  - good fasteners (avoid rail rotation)
  - good welds (avoid dipping)
  - high strength steels
  - regularly grind to remove weak material
- Know the condition
  - Non-destructive testing
  - Eddy current or vision system
  - Current state of profiles
  - Plastic flow

What does the future hold?

- Better rail steels?
- Improved inspection
- Friction management
- Site specific rail profiles?
- Reliable quantification of surface damage
- Improved grinding/milling technology and application
- Quantifying the benefits

Vancouver, Canada
July 23-25, 2019
http://www.icri-rcf.org/icri-workshop/workshop-info/

Friction: management, modeling
Rail grinding quality, Rail milling
Safety and Risk
Locomotive adhesion
Wheel shelling
RCF – quantifying damage, modeling
VTI Economics

Thank You

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