Rail & Wheel Profiles: The Nexus of Wheel/Rail Interaction

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Combatting Wear and RCF

1. Wheel and rail profiles
2. Friction management and lubrication
3. Steel metallurgy (hardness, cleanliness)
4. Bogies/trucks (soft vs hard suspension, body steered, self-steering)

• All of them are equally important
• All of them should be used
Looking Back – Rail Profiles

• Softer rail steels – rapid initial wear, plastic flow
• Grinding to remove corrugation, not to attain a specific target profile
• Grinding templates not in use
• No asymmetric profiles = poor steering and high wear
• AREA / AREMA recommended rail profiles
Looking Back – Wheel Profiles

• Worn wheel limits did not include hollowing
• Interchange freight profile was prescribed
• Limited choice for intercity service
• More choice for transit – how to choose?
Looking Back – Friction Management

• Gauge face lubrication – spotty
  – Equipment not sophisticated
  – Output not well-controlled
  – Choice of product at the discretion of local people

• TOR-FM – not invented
  – Positive, neutral, negative friction characteristic?
Past, Present and Future

What happens if I choose incompatible profiles?
Wrong Profile Combination?

Wrong combination of W/R profiles can lead to high flange and gauge face wear.
Wrong Profile Combination?

Wrong combination of W/R profiles can lead to rail (sub)surface damage
Wrong Profile Combination?

Wrong combination of W/R profiles can lead to wheel surface damage.

- Ratcheting micro-cracks
- Fully shelled wheel
Wear and RCF Damage

- Flaking
- Rolling Contact Fatigue Cracks
- Plastic Flow
- Typical Inner (Low) Rail Wear
- Typical Outer (High) Rail Wear
- Gauge Side Wear (Gouging)
- Shell Spots
- RCF Cracks
- Plastic Flow
- Track Gauge
- Field Side
Why Manage W/R Profiles?

• Each wheel rail system is unique due to its traffic mix, prevailing bogie suspension and distribution of track curvature – one combination of wheel and rail profiles does not fit all systems

• The choice of available new wheel and rail profiles can reduce or hasten wear, RCF and development of corrugations

• Optimizing and maintaining wheel/rail profiles by periodic re-profiling extends life, reduces vehicle and track maintenance and maintains vehicle stability
W/R Contact Points are Mirror Images

\[ N_W = N_R \]
\[ T_W = T_R \]

\[ P_{0W} \approx P_{0R} \]

\[ \tau_{\text{MAXW}} \approx \tau_{\text{MAXR}} \]
The Impact of Profiles

• Fatigue (of wheels and rails)
  – rail: 2.2 to 4 million cycles/ 100 MGT
  – wheel: 56 million cycles / 100,000 miles
  – controlled by grinding (rails), truing (wheels), milling (both)

• Wear (of wheels and rails)
  – also lubrication

• Stability
Freight vs High Speed

• Freight trains
  – heavy axle loads (35 kip)
  – slow (30-60 mph)
  – runs under-balance in mixed traffic system
  – relatively flexible bogies

• High Speed
  – light axle loads (25/16 kip)
  – high speed (110 to 150 mph)
  – runs over-balance in mixed traffic operations
  – longer wheelbase, light and stiff bogies
Wheel/Rail Profile Design (the 5 C’s)

• Conformality
• Contact Stress
• Conicity
• Curving
• Creepage
1. Conformality

- **closely conformal**
  - 0.1 mm (0.004”) or less
- **conformal**
  - 0.1 mm to 0.4 mm
  - (0.004” to 0.016”)
- **non-conformal**
  - 0.4 mm (0.016”) or larger

![Diagram illustrating conformality](image)
Conformality on Tangents
2. Contact Stress

- Depends on
  - wheel radius
  - wheel load
  - wheel/rail profile
  - friction coefficient
Shakedown
Excessive Contact Stress

Gage corner collapse

Concave low rail

Cracked high rail
3. Conicity

Input/Output Values

- $L_{\text{load}}$: 5100
- $R_{\text{load}}$: 5100
- $a_{\text{ol}}$: 0
- $R_{\text{right}}$: 0.33
- $R_{\text{left}}$: 0.33
- $\text{CurveRadius}$: 100000
- $dR$: 0.0
- $\text{Smrment}$: 0.0
- $\text{Drag}$: 0.0

Graphs showing effective conicity and contact stress over wheel offset.
Conicity – the general case

• British Rail derivation

\[ \lambda_e = \frac{1}{2} \int \frac{N(y) (r_R - r_L)}{y} \, dy \]
4. Wheelset Curving

Rolling radius difference achieved by conical wheels in curves
Also by using asymmetric rail profiles

T: tangent  H: high rail  L: low rail
Rolling Radius Difference

- not enough (insufficient):
  - poor steering, flanging, wear, noise
  - e.g. new wheel on worn high rail

- just enough:
  - perfect steering, free rolling
  - e.g. asymmetric grinding + steered bogies

- too much (excessive):
  - mild curves - to overcome suspension resistance
  - yields longitudinal creep forces
Rolling Radius Difference ($\Delta R$)

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<th>Curve R [m]</th>
<th>Curve R [ft]</th>
<th>Curvature (degree)</th>
<th>dR [mm]</th>
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Wheel radius = 14.5” (0.3683 m)
Gauge = (1680+50)mm = 68-1/8”
5. Creepage (slip)

\[ \Psi_x = \frac{\nu_1 - \nu_2}{\frac{1}{2}(\nu_1 + \nu_2)} \]

longitudinal

\[ \Psi_y = \frac{\nu_1 - \nu_2}{\frac{1}{2}(\nu_1 + \nu_2)} \]

lateral

\[ \phi = \frac{\omega_1 - \omega_2}{\frac{1}{2}(\nu_1 + \nu_2)} \]

spin

Creepage: impacts:
- wear
- fatigue
- L/V forces
- traction/adhesion

\[ \omega_1 = 0 \]

\[ \omega_2 = \frac{v_2}{r} \cos \alpha \]
Lateral Forces (Creep) in Curves

Direction of Travel

Contact Patch

Longitudinal Creepage

Spin Creepage

AoA
Design Objectives

- **High Speed**
  - stability
  - noise
  - wear
  - corrugation
  - fatigue

- **Heavy Haul**
  - contact fatigue
  - (curve) wear
  - stability
  - corrugation
  - noise

Compromise design via pummelling
Wheel Profile Design

Flange root: steering

Wheel tread: stability

Field side steering, contact stress

H.R.  T.T.  L.R.
“High conicity” Anti-Shelling Wheel (ASW) profile designs reduced RCF shelling by 18 – 60% on various railroads.
Example: Acela Wheel Profile
Rail Profile Design - Pummelling
Pummelling Analysis

• Simulation
  – measured wheel profiles
  – vehicle characteristics (stiffness, wheelbase etc.)
  – rail hardness (for damage evaluation)
  – rail curvature, super-elevation, dynamic rail rotation etc.

• Evaluate distributions of
  – contact stress
  – steering moments
  – effective conicity
Pummelling Tool
Looking Ahead…

• Smarter profile design tools
  – Define an objective function, tolerance, number of iterations permitted
  – Genetic algorithms

• Steels with increased damage/wear resistance

• Increased use of
  – flexible (yaw) trucks on freight
  – Steered trucks on transit

• Widespread use of friction management

• Route-specific rail profiles
Questions?