Wheel life prediction model considering wear and RCF: LKAB Iron-Ore Loco

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Background

The Iron Ore Line (Swedish: *Malmbanan*) is around 470Km.

Extreme Weather conditions in summer and winter
Background

Wheels regular **Inspections**: every 26’000 km (locos) and 80 000km (wagons)

Wheel **Re-profiling**: every 40 000 km (locos) and 250 000 km (wagons)

Wheel **Life**: 400 000 km (locos) and 1 000 000 km (wagons)

Main reason: **Rolling Contact Fatigue**

Is ED braking the source of the problem?

Using dynamic simulations

Model Wear & RCF
Amsted **Three-Piece Bogie** with load sensitive friction damping

**Axle load**: 30tons

Max. **speed** on tangent track: 60km/h (Laden) - 70km/h (Un-laden)

MBS software **GENSYS** is used to perform dynamic simulations
Methods and Theories: Wear

Archard Wear Map

\[ \Delta \zeta = k \frac{p \Delta s}{H} \]

Wear depth:

- Start wheel profiles
- Load collective design
- Vehicle-track simulations
  - Wheel-rail contact response
- Wear calculation
  - Profile updating
- Desired distance attained?
  - No (new wear step)
  - Yes (finished)

Track data:
- Coefficient of friction
- Braking and acceleration
- Vehicle traffic conditions
- Design geometry
- Rail profiles
- Track irregularities
- Environmental parameters
Braking & Acceleration

DT = Mechanical res. + Aerodynamic res. (Da) + Curve res (Dc) + Gradient res (Dg)

Graphs showing the distribution of gradient per mil in Sweden and Norway.

Drag Force
Methods and Theories: RCF

\[ K = \text{material yield stress in shear} \]
Methods and Theories: RCF

Operational conditions (including high and low estimates of wheel–rail friction) for all tests plotted in a shakedown map. **RO: roller rig, TD: twin disc, LI: linear rig**

\[ F_{I_{surf}} = 1.78(N_f)^{-0.25} \]
Methods and Theories: Palmgren-Miner Rule

\[ \sum_{i=1}^{k} \frac{n_i}{(N_f)_i} = C \]

\[ (N_f)_{Total} \sum_{i=1}^{k=9} \frac{d_i}{(N_f)_i} = 1 \]

\[ F_{surf} = 1.78(N_f)^{-0.25} \]

Simulation results: Calculated for each curve in various conditions.
(averaged for different friction values 0.35(Low):0.65(High))
## Simulation cases

<table>
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<th>Radius interval (m)</th>
<th>Radius(m)</th>
<th>Transition (m)</th>
<th>Constant curve(m)</th>
<th>d(i) (%)</th>
<th>Cant(mm)</th>
<th>Gauge(mm)</th>
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How can we consider the effect of wear on RCF?

How can we find positions, length and angle of the cracks?

Unlike the lab. results not all the revolutions have positive FIsurf values.
Methods and Theories: Life estimation flowchart

Start wheel profile

Load collective data

Vehicle-track simulations
Wheel-rail contact response

Inputs: Track data; rail profiles, irregularities, friction level, Vehicle traffic condition

Check the $F_{1surf}$ positive values in each wheel revolution

Find the positions on the wheel; Calculate and mesh the contact patch ellips (Hertz)

Count the number of rotations with positive $F_{1surf}$ in each mesh along the line. Scale the values by Energy dissipation.

Reach the $(N_f)_{Total}$?

Yes!
Reach the wheel life [km]

No!

Update the wheel profile

Wear calculation
Comparison of the measured and simulated loco original wheel profiles after 40’000 km

Results: Wear / Profile evolution

Comparison of the measured and simulated loco original wheel profiles after 40’000 km
Results: one wear step: 470 km

- Contact patch is assumed to be symmetric; Only half of the patch is shown.
- Size of the cracks: Diameter of the ellipse at the failure

![Inner wheel](image1)

![Outer wheel](image2)
Results: RCF severity after 20’000 km

\[ N_{f_{\text{Total}}} \text{ (Failure limit)} = 5 \times 10^4 \text{ wheel revolutions} \]
Results: RCF severity after 30’000 km

\[ N_{f_{\text{Total}}} \quad \text{(Failure limit)} = 5E4 \text{ wheel revolutions} \]
Results: RCF severity after 40’000 km

25% braking

0% braking

$N_f^{\text{Total}}$ (Failure limit) = 5E4 wheel revolutions
Results: Angle of the cracks after 50’000 km, Inner wheel

25 % braking

0 % braking
25 % braking

0 % braking

Shear force angle (degree)

Outer wheel flange root

Lateral position of the wheel (mm)

Shear force angle (degree)

Outer wheel flange root

Lateral position of the wheel (mm)

Shear force angle (degree)

Outer wheel flange

Lateral position of the wheel (mm)

Shear force angle (degree)

Outer wheel flange

Lateral position of the wheel (mm)
Results: Profile evolution after 50’000 km
Conclusions

The wheel life prediction method is using:
- Shakedown theory based RCF estimation,
- Archard map based wear calculation,
- Dynamic simulations
- Laboratory tests
- Palmgren – Miner rule for cumulative damage model

A good agreement between the observations and calculation results are achieved:
- The running distance until the surface cracks are visible on wheels
- Wheel profile evolution due to wear after 40 000km

ED braking is not the source of the short wheel life. (Agrees with the field Tests)
Thank you very much for your attention

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