WHEEL/RAIL CONTACT GEOMETRY PARAMETERS IN REGARD TO VEHICLE BEHAVIOUR AND THEIR ALTERATION WITH WEAR

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Content

- Contact geometry parameters in regard to running dynamics
  - Alteration of wheel/rail contact geometry parameters with wear
  - New contact geometry parameters versus contact spreading
  - Comparison with other publications
  - Comparison of design wheel/rail profile combinations
  - Conclusions
Motivation for extended characterisation of wheel/rail contact geometry

- The actual wheel/rail contact geometry changes due to wear of wheels and rails.
- Equivalent conicity is used to characterise the contact geometry in regard to hunting and critical speed.
- However, one value of equivalent conicity can represent very different contact geometries!

Ref.:

- Does the shape of equivalent conicity function influence the vehicle dynamic behaviour?
- Do we need to extend the characterisation of wheel/rail contact geometry?
- Yes: A new contact geometry characterisation using two parameters was proposed on the IAVSD Symposium in Stockholm 2009 [1]
Contact geometry and vehicle behaviour at the stability limit

Equivalent conicity function

Wheel/rail contact geometry A

Wheel/rail contact geometry B

Bifurcation diagram

Wheelset amplitude [mm]

Speed [km/h]

Wheel/rail contact geometry A

Wheel/rail contact geometry B

Wheelset amplitude [mm]

Speed [km/h]
Contact geometry and vehicle behaviour at the stability limit

Equivalent conicity function

Bifurcation diagram: Vehicle 1

Bifurcation diagram: Vehicle 2

Bifurcation diagram: Vehicle 3
Contact geometry and stability in simulations on track with irregularities and on ideal track geometry

Run on measured track irregularities

Wheel/rail contact geometry A

Wheel/rail contact geometry B

Behaviour following a single excitation

Wheel/rail contact geometry A

Wheel/rail contact geometry B

Sum of guiding forces (UIC 518)

Acceleration, rms value

Limit cycle ≈ safety limit

Limit cycle

Safety limit
Nonlinearity Parameter (NP)
Characterisation of contact geometry by two parameters

- **Parameter 1 – Level parameter:**
  - **Definition:**
    - Equivalent conicity for a wheelset amplitude of 3 mm
  - **Usage:**
    - Assessment of contact geometry in regard to the safety relevant instability limit according to EN 14363

- **Parameter 2 – Nonlinearity parameter:**
  - **Definition:**
    - Slope of the equivalent conicity function
  - **Usage:**
    - Vehicle performance at the stability limit
    - Sensitivity of the vehicle to the lateral excitation by track irregularity
  - **Definition:**
    \[
    NP = \frac{\lambda_4 - \lambda_2}{2} \quad [1/mm]
    \]

Ref.:
Characterisation of wheel/rail contact geometry: Aim of the presentation

- The same equivalent conicity at the wheelset amplitude of 3 mm
- Different contact geometries:
  - Type A: NP > 0, Type B: NP < 0

No information about the in service values of nonlinearity parameter (NP) and its alteration due to wear of wheels and rails were presented so far.

This paper describes recent investigations on a large amount of measured wheel and rail profiles and shows the typical development of NP due to wear.

A hypothesis explaining the observed relationship in regard to the spreading of the contact between wheel and rail is presented.

A new parameter for assessing the concentration of contact points is proposed and suggestions for the usage of this parameter are presented.
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Evaluation of wheel profile measurements of the German high speed trains ICE 3

- Wheel profile measurements on high speed trains ICE 3 conducted in 2003
- In total 9,030 measured wheelsets
- Calculation of equivalent conicity:
  - Measured wheel profiles
  - Rail 60E1 (formerly UIC 60), inclination 1:40 (at that time the nominal conditions on the most German lines)
  - Nominal track gauge 1435 mm

Figures: www.hegenscheidt-mfd.com
Conicity and NP of measured wheel profiles of the German high speed trains ICE 3

- Evaluation of measured wheel profiles of fleet ICE 3 in combination with nominal rails and nominal track gauge
- Development of equivalent conicity and nonlinearity parameter (NP) with wear with increasing running distance
- The evaluation shows that the equivalent conicity increases while NP decreases with increasing running distance
Evaluation of wheel profile and rail profile data in the framework of research project DynoTRAIN

Project DynoTRAIN:
- Team: 22 partners
- Duration: June 2009 – September 2013
- Objectives:
  - To harmonise European and national standards on railway dynamics
  - To reduce costs of authorization by an increasing use of simulations for vehicle acceptance

Analyses of measured wheel and rail profile data in DynoTRAIN WP3:
- Samples of wheel and rail profile data were provided by project partners
- Wheel profiles:
  - Altogether more than 55,000 wheelset profiles
  - Measured wheel profiles from:
    - high speed trains ICE and TGV, passenger coaches, locomotives, EMU, DMU and freight wagons
    - vehicles operated in Germany, Austria, France, Italy, Switzerland, UK, Hungary and Slovenia
- Rail profiles:
  - Altogether more than 300,000 rail profiles
  - Measured rail profiles from Germany, France, Italy, UK
- The wheel and rail profile pairs were evaluated in groups according to country and speed category

DynoTRAIN test campaign in Germany, France, Italy and Switzerland, October 2010
Relation between NP and equivalent conicity

- Results from DynoTRAIN (measured wheel and rail profiles)
  - High scatter, but the same trend in all categories
  - The trend is the same as observed in the evaluation of ICE wheel profiles on new rails
  - In average, NP decreases with increasing conicity
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Hypothesis explaining the relationship between conicity and NP

- The described phenomenon can be explained by an increase of contact conformity with running distance.

![Diagram showing wheelset displacement and contact point movement with worn and heavily worn wheel profiles.](image-url)
Analysis of wheel profile alteration with wear

- Measured wheel profiles of a German ICE 2 high speed train (nominal wheel profile S1002 with reduced flange thickness) was evaluated to confirm this hypothesis.
- The wheel profile data were sampled systematically during a test of different wheel profile designs in 1998.
- Measured wheel profiles are analysed in combination with nominal track parameters (track gauge 1435 mm, rail 60E1 1:40).
- The analysis confirms that wheel wear results in a change of the contact geometry from Type A to Type B with increasing running distance.
Parameters describing the contact spreading

Contact point movement

- Contact point movement $d_{yC}$ over the lateral wheelset displacement $y_{WS}$

$$d_{yC}(y_{WS}) = \left| \frac{\Delta y_{C}(y_{WS})}{\Delta y_{WS}} \right| = \frac{y_{C}(y_{WS} + \Delta y_{WS}) - y_{C}(y_{WS})}{\Delta y_{WS}}$$

Example:
Wheel profile S1002,
Rail 60E1 1:40,
Track gauge 1435 mm
Parameters describing the contact spreading

Contact bandwidth change rate

- Contact bandwidth change rate $d_{LW}$ is proposed by Gan and Dai in [2].
- This parameter considers a lateral wheelset movement with an amplitude $A_{WS}$.
- The distance between the contact point location for $y_{WS} = -A_{WS}$ and the contact point position for $y_{WS} = A_{WS}$ is defined as contact bandwidth $L_{W}$.

$$L_{W}(A_{WS}) = y_{c}(-A_{WS}) - y_{c}(A_{WS})$$

- **Contact Bandwidth Change Rate** $d_{LW}$ is the ratio of the contact bandwidth and the respective lateral wheelset displacement:

$$d_{LW}(A_{WS}) = \frac{L_{W}}{2A_{WS}}$$

Example:
Wheel profile S1002,
Rail 60E1 1:40,
Track gauge 1435 mm

Ref.:
New parameters describing the contact spreading
Contact Concentration and Contact Concentration Index

- **Contact Concentration** $c_c$
  - Characterises the frequency of the contact point occurrence across the wheel profile
  - Provides an indication of the wear distribution
  - Assumptions used:
    - Straight track; stochastic lateral wheelset displacement with normal distribution with standard deviation $\sigma$ (here $\sigma = 2.5$ mm selected)
    - It is assumed that the local wear of wheels and rails is related to the local frequency of contact point occurrence
  - Contact concentration represents a reciprocal contact point movement $dy_C$ multiplied by the respective percentile $p_{y_{WS}}(y_{WS})$ of the wheelset displacement occurrence

$$c_c(y_{WS}) = \frac{p_{y_{WS}}(y_{WS})}{dy_C(y_{WS})}$$

- **Contact Concentration Index** $CCI$
  - Characterises the average contact concentration properties of the respective combination of wheel and rail profiles by one value
  - Is defined as an average value of the contact concentration $c_c(y_{WS})$ over the normal distribution between $-3\sigma$ and $3\sigma$ of the lateral wheelset displacement

$$CCI = \frac{1}{n} \sum_{i=1}^{n} \frac{p_{y_{WS}}(y_{WS_i})}{dy_C(y_{WS_i})}$$

Example:
Wheel profile S1002, Rail 60E1 1:40,
Track gauge 1435 mm
Alteration of contact parameters with vehicle’s mileage

- Contact point movement increases with wear
  - The largest contact point movement occurring at new wheel profiles for wheelset displacements between 1 and 2 mm is approximately doubled at worn wheel profiles and shifted closer to the centred wheelset position
- A contact point movement increasing with wear results in a wider spread of wear in rolling contact; this is indicated by the increase of contact bandwidth change rate with wear, particularly for small wheelset displacement amplitudes just after re-profiling
- The wider spreading of contact points at worn wheels is documented by decreasing contact concentration, particularly for small wheelset displacements close to zero
Relationships between equivalent conicity, nonlinearity parameter (NP) and contact concentration index (CCI)

- Equivalent conicity increases while NP decreases with increasing mileage
- Equivalent conicity is indirectly proportional to CCI; this confirms the presented hypothesis that the conicity increase is accompanied with wider contact spreading, i.e. lower contact concentration
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Results from other authors

- High speed vehicles in China with wheels turned to design profile LMA [3]
- Alteration of equivalent conicity and NP with mileage shows the same tendency as on ICE high speed trains in Germany

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Comparison of contact geometry and contact spreading parameters of selected design profiles

1) Wheel profile S1002, rail 60E1 1:40
   - Wheel profile S1002 was proposed as wear adapted profile by the expert committee ORE S1002 in 1973
   - It is very close to the wear adapted profile evaluated in Germany with rail inclination 1:40

2) Wheel profile P8 BR, rail BS 113A 1:20
   - Wheel profile introduced in UK, developed based on experience with vehicles in UK in service on tracks with rail inclination 1:20

3) Wheel profile EN 13715 - 1/40, rail 60E1 1:20
   - Conical wheel profile with tread inclination 1:40

4) Wheel profile S1002, rail 60E1 1:20

5) Wheel profile EN 13715 – EPS/h28/e32.5/10%, rail 60E1 1:40
   - Wheel profile with the tread shape identical to P8 BR but flange thickness of 32.5 mm
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Conclusions
Conclusions

- Nonlinearity Parameter (NP) extends the characterisation of wheel/rail contact geometry using the equivalent conicity for a wheelset displacement amplitude of 3 mm by an auxiliary information related to the dynamic vehicle behaviour.

- This parameter can be applied for:
  - assessment of profile measurements with the aim to improve the characterisation of wheel/rail contact geometry in regard to the dynamic vehicle behaviour.
  - use of profile combinations in simulations to allow better selection of wheel and rail profiles intended to be used as representative contact geometries.
  - design of new wheel profiles because it provides an indication of profile shape stability: profile combinations with negative NP can be expected to keep their form longer than those with positive NP.

- Starting with a new wheel profile, the equivalent conicity usually at first increases while NP decreases with increasing mileage.

- The increase of equivalent conicity is provided by increasing conformity and larger contact spreading; therefore, the wheel profile shape gets more form stable at high mileage.

- A new parameter called Contact Concentration Index (CCI) is proposed to assess the contact conformity.

- CCI as well as the recently proposed Contact Bandwidth Change Rate were evaluated on samples of measured wheel profiles as well as on selected combinations of design wheel and rail profiles.

- Both parameters are related to the development of the equivalent conicity due to wear; the profile combinations with high Contact Bandwidth Change Rates and small CCI will be more form stable, i.e. the tread part of the wheel profile will keep its shape.
Thank you for your attention!

Questions?