Methods for Running Stability Prediction and their Sensitivity to Wheel/Rail Contact Geometry

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- Comparison of resultant critical speeds
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Motivation

Typical task during the suspension design of railway vehicles:

- What is the maximum speed at which the vehicle will run stable for the specified equivalent conicity?
  or
- Which suspension parameters are needed to run stable for the given speed and equivalent conicity?

Questions to solve by the specialist:

- Which method and criteria should be used?
  and
- How to model the specified equivalent conicity in the nonlinear simulations?
Bogie and Carbody Stability

Critical speed

Equivalent conicity

stable area

0% of critical damping

5% of critical damping

Carbody hunting

Bogie hunting
Definition of Stability Limit

Difference: Mechanics – Railway Standards

<table>
<thead>
<tr>
<th>Mechanics</th>
<th>Railway Standards</th>
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<td>stable</td>
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<td>unstable</td>
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![Graphs showing stable and unstable conditions for both Mechanics and Railway Standards.](image-url)
Classification of Methods for Stability Analysis

- **Vehicle Model**: Linear, Nonlinear
- **Wheel/Rail Contact**: Linear, Nonlinear
- **Calculation Method**: Eigenvalue analysis, Simulation
- **Excitation Type**: No excitation, Single excitation, Stochastic excitation
Simulation of Run with Decreasing Speed (No Excitation)
Excitation by a Single Lateral Irregularity

stable

unstable
Bifurcation Diagram

Amplitude of the limit cycle as function of speed

- Lateral amplitude
- Speed
- Stable area
- Unstable area
- Unstable saddle-cycle
- Stable cycle
- $V_{cr}$
Simulation of Run on Measured Track Irregularity

Limit values according to standards (UIC 518, prEN 14 363):

- Acceleration, rms value
- Sum of guiding forces, rms value
Vehicle Model

- A four-car articulated vehicle modelled in Simpack
- Wheel/rail friction coefficient 0.4 (dry)
Examples of Contact Geometry Wheelset/Track

- Equivalent conicity: Specified for wheelset lateral amplitude of 3 mm
- Four examples of wheel/rail contact geometry

04A

06A

04B

06B
Equivalent Conicity Function

Conicity 0.4

Conicity 0.6
Simulations of Run with Decreasing Speed

Conicity 0.4

Conicity 0.6
Method with Single Excitation

Conicity 0.4

04A

Conicity 0.6

06A

04B

06B
Bifurcation Diagrams

Conicity 0.4

Conicity 0.6

04A

04B

06A

06B
Simulations of Run on Measured Track Irregularities

- **Speed 270 km/h**
  - Lateral acceleration, time signal
  - Lateral acceleration, rms value (UIC 518)
  - Sum of guiding forces, rms value (UIC 518)

- **Speed 280 km/h**
  - Lateral acceleration, time signal
  - Lateral acceleration, rms value (UIC 518)
  - Sum of guiding forces, rms value (UIC 518)
Results of Simulations on Track Irregularities

**Conicity 0.4**

- 04A

- 04B

**Conicity 0.6**

- 06A

- 06B

- Sum of guiding forces (UIC 518)
- Acceleration, rms value (UIC 518)
- Acceleration, peak value (UIC 515)
- Limit value
Dynamic Behaviour after a Single Excitation

**Speed 260 km/h**

- **Acceleration on bogie frame - time signal**
- **Acceleration on bogie frame - rms value**
- **Sum of guiding forces - rms value**

**Speed 280 km/h**

- **Acceleration on bogie frame - time signal**
- **Acceleration on bogie frame - rms value**
- **Sum of guiding forces - rms value**
Stability Assessment of Behaviour after a Single Excitation

04A

04B
Comparison of Resultant Critical Speeds

Conicity 0.4

Contact geometry

Critical speed [km/h]

- No excitation, decreasing speed
- Bifurcation diagram
- Single excitation, oscillation damped
- Single excitation, sum of Y-forces, rms value [UIC 518]
- Single excitation, acceleration, rms value [UIC 518]
- Single excitation, acceleration, peak value [UIC 515]
- Track irregularity, sum of Y-forces, rms value [UIC 518]
- Track irregularity, acceleration, rms value [UIC 518]
- Track irregularity, acceleration, peak value [UIC 515]
Comparison of Resultant Critical Speeds

Conicity 0.6

Critical speed [km/h]

0 50 100 150 200 250 300

06A 06B

- No excitation, decreasing speed
- Bifurcation diagram
- Single excitation, oscillation damped
- Single excitation, sum of Y-forces, rms value [UIC 518]
- Single excitation, acceleration, rms value [UIC 518]
- Single excitation, acceleration, peak value [UIC 515]
- Track irregularity, sum of Y-forces, rms value [UIC 518]
- Track irregularity, acceleration, rms value [UIC 518]
- Track irregularity, acceleration, peak value [UIC 515]
Conclusions (1): Nonlinear Method for Stability Analysis

- Difference in definition of stability between Mechanics and Railway Engineering
- The methods presented are comparable if no limit cycles with small amplitude occur
- For a specified conicity, differences between the results occur dependent on the method, limit value and the contact geometry
- If small limit cycles occur stability limits from the railway standards should be used to judge the results
Conclusions (2): Specification of Wheel/Rail Contact

- Specification of the shape of wheel profile, rail profile, rail inclination and gauge
- Separate specification of the maximum wheelset related equivalent conicity and the maximum track related equivalent conicity
- Only the maximum equivalent conicity specified: Recommended to use wheel/rail contact geometry with increasing or constant conicity function to avoid small limit cycles