Low Adhesion Braking Model

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Introduction

- Wheel-rail adhesion varies considerably due to various factors
  - weather conditions
  - leaf-contamination of the rail
  - drying and cleaning effects of successive wheelsets
- Low adhesion limits accelerations during traction and decelerations during braking which can seriously compromise safety and network performance.
- Wheel slide protection (WSP) and sanding are used to increase adhesion in an attempt to avoid wheel damage / flats and to minimise braking distance.
- In extreme situations, long train slides can occur with consequential risk of collisions with other trains:
  - SPADs (signals passed at danger) or with buffers at terminal stations.
Introduction

Image courtesy Rail Accident Investigation Branch
**Aim**

**LABRADOR – Low Adhesion Braking Dynamic Optimisation for Rolling Stock**

**Aim:** To develop simulation software capable of modelling the behaviour of modern multiple unit passenger trains braking under low adhesion conditions by representing the complex interdependence of brake system components in the overall behaviour of the brake system.
Brake Control System (Simplified)

Courtesy of northern
Summary of model capabilities

• 1, 2, 3, and 4 car train models – user defined parameters
• User configurable braking arrangement & controller architecture
• Variable gradient and adhesion profiles
• Constant and variable brake command
• Configurable WSP function
• Dynamic brake with blending and over-braking
• Sanding and drying effects
• Weight transfer due to pitch effects (body and bogie)
• Tread damage due to wheel slide predicted
• Air consumption – sanding and braking (WSP)
• Models are fully configurable via a Graphical User Interface (GUI)
Model fundamentals - LABRADOR

\[
\ddot{x}(t) = \frac{1}{M} \left( -F_{fb_1}(t) - F_{fb_2}(t) - F_{fb_3}(t) - F_{fb_4}(t) - F_w(t) - F_{grad}(t) \right)
\]

- Where: \( M \) is the total mass; \( F_{fb_j} \) is the braking force in the \( w-r \) contact; \( F_w \) is the aerodynamic drag and \( F_{grad} \) is the longitudinal/horizontal component of the vehicle weight due to the track gradient.
- Empirical expressions (Davis equation) used to estimate aerodynamic drag i.e. \( F_w(t) = A + B \cdot \dot{x}(t) + C \cdot [\dot{x}(t)]^2 \). See Rochard and Schmid (2000)
WSP & dynamic brake

- Three WSP models
  - Simple on/off
  - BR WSP
  - 1990s WSP with hold function (ref Barna)

- Currently assumes:
  - Perfect knowledge of train speed
  - No air supply limitations

- Dynamic brake with user defined characteristics
  - Can overbrake for adjacent trailer wheels/vehicles
  - Isolated when WSP active

Decision table of a WSP system control algorithm (Boiteux (1999) as cited in Barna (2012)).

<table>
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<th>a</th>
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<th>a4</th>
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Brake Force (kN) vs Speed (km/h)

- DB Force
- Total Force
- FB Force
Wheel-rail contact

- Initial model used simple Coulomb friction
- More complex Polach model (non-linear falling creep curve)
  - Assumes constant contact patch size
  - No tangential creep forces considered
- Drying effects assumed per wheel
- Sanding increases $\mu$ at following wheel by approx. 0.15 (@2kg/min)
  - Then reduces by 66% at each following wheel
  - Some data available on effect of sanding rate
- Opportunity to validate further
Wheel thermal damage model

• Wheel damage arises if wheel remains locked for long enough to exceed the steel phase transition temperature

• Hard brittle martensite forms – shelling and cavities

• LABRADOR uses BR Research / Tanvir model
  • Very sensitive to contact patch size

\[ \theta_w = \theta_r = \frac{2.26 \times P_m \cdot \mu \left( \frac{a \cdot \alpha \cdot V}{\pi} \right)^{1/2}}{K} \{1 - (1 - R)^{1/2}\} \]

\( \theta_w \) and \( \theta_r \) = interface temperatures of the wheel and the rail
\( P_m \) = maximum pressure
\( \mu \) = w-r friction coefficient
\( K \) = thermal conductivity
\( a \) = longitudinal semi-axis of the contact ellipse
\( \alpha \) = thermal diffusivity
\( V \) = vehicle speed
\( R \) = slip ratio
LABRADOR model hierarchy

Inside the four car model there are four vehicle subsystems and auxiliaries sub-models (e.g. train dynamic model, train mass profile, train brake controller, and environment model, ...)
Inside the vehicle subsystem there are 2 bogie subsystems, and auxiliaries subsystems (e.g. weight transfer subsystem, vehicle brake controller)
Inside the bogie’s subsystem there are two wheelsets’ subsystems
Inside the wheelset subsystem there are WSP, Sander, and wheel subsystems.
Inside the wheel subsystem there are contact patch, temperature, and adhesion subsystems.
Sample simulation results

Class 158 for full service brake application (notch 3) – experimental and simulation data showing effect of low w-r friction on stopping distance
Next steps

• Implement Sheffield / Virtual Vehicle WILAC model from T1077

• Model testing and validation

• User testing

• WSP speed estimation (dependable speed measurement project)

• Longer trains

• More sophisticated WSP models

• Hardware-in-the-loop implementation?
Dynamic test rig overview (HAROLD)
Conclusions

• LABRADOR can simulate braking system configurations for different trains under varying track gradient and adhesion profiles

• Modularity of the various sub-systems is preserved

• This enables the model to be extended to represent longer trains and to model brake systems for older, contemporary and future rolling stock

• LABRADOR will allow the study of specific brake control features such as WSP strategies, sanding effectiveness, dynamic brake utilisation, traction performance, etc.

• This understanding will help train operators, maintainers and integrators to optimise the braking performance of their trains.
Acknowledgements

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