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Project title

IMPACT LOAD ANALYSIS OF HEAVY HAUL 3-PIECE BOGIE ORE CARS

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Research Academy theme/s

1. Advanced computational engineering, simulation and manufacture
2. Infrastructure engineering

The problem

Contact conditions between the wheel and rail involved a combination of rolling and sliding contact, commonly referred to as mixed rolling/sliding contact. Material damage modes that develop as a result of these contact conditions involve material loss (wear), and the development of surface-initiated cracking (rolling contact fatigue). The inter-relationship between wheel/rail contact conditions and material response is well understood for steady state conditions.

Transient wheel-rail contact conditions may arise from a number of causes: impact loading at vertical irregularities (rail welds, insulated rail joints and rail corrugations etc), and as a result of wheel slip under traction or wheel slide under braking. The latter generally result in material damage on both rails.

A particular form (rail squats) of rolling contact fatigue damage, possibly associated with transient behavior at the wheel/rail interface, has become more common in both mass transit, freight and heavy haul rail systems. Examination of damaged rails indicates that damage initiation and propagation behavior is not easily explained for current models for wheel-rail contact and material damage. One suggestion is that damage initiation is due to localized, random events that involve fluctuations on both vertical load (and hence contact stress) and creepage, and which may also result in transient temperature increases below the contact patch. Material response under these conditions is likewise not well understood.

With the increase in axle load, the interaction between the vehicle and track has become more intensive. Most track damage is caused by impact forces. Wheel/rail irregularities such as wheel flats, wheel shells, rail joints and rail corrugations are major sources that cause severe dynamic forces. Rail joints are one of the weakest parts in the track components. The dynamic interaction between wheel and rail joints not only damages the rail, but also degrades the cross ties, fasteners, ballast and even the subgrade. Many track maintenance problems can be traced back to the rough-ride conditions caused by rail joints. Welds exhibit discontinuities on the rail running surface, due to variation in material characteristics (strength, hardness and microstructure), misalignment at the rail ends prior to welding, running surface irregularities caused by hand-grinding after welding, and subsequent weld batter. In addition, welded rail joints may contain weld defects and high residual stress levels. All of these are combined to produce high, localized wheel/rail impact forces. These high impact loads increase the potential of fatigue failure of the weld, and accelerate the settlement and deterioration of the track components. In return, the enlarged track deformation increases impact loads. Cracks, squats and spalling emerged at rail welds after increasing axle loads. The welds produce high maintenance costs and are one of the main risks for catastrophic derailments.

There has been few research results published that systematically analyze the dynamic impact forces at the rail weld joints based on the vehicle and track coupling system. In this project, a 3D coupled vehicle/track model is developed first and then used to analyze the effect of welded rail joint irregularities on the impact forces at high axle load conditions.

In the model, a full vehicle is considered, and the vehicle is modeled as a multi-body system. 3-piece bogie with built-in or split wedge damping is considered. For the track model, the rail is modeled as a Timoshenko beam resting on discrete sleepers. Finite element method (FEM) is used to describe the dynamic behaviour of the Timoshenko beam. The ballast bed is replaced with equivalent lumped masses.

The weld rail irregularity is modeled as a local track vertical deviation. In the numerical analysis the effect of the different wavelength and depth of the irregularity, the position of the welded joint in a sleeper span, and vehicle speed is taken into account.

Project aims

- Most multi-body dynamics commercial software packages such as Vampire Pro mainly focus on vehicle part only and significantly simplify the track substructure. Moreover the simulated results of high frequency response due to impact load are not good by using these commercial software packages. Thus, the first objective of this project is to build a complete 3D model of vehicle-track coupled dynamic system focusing on 3-piece bogie vehicle (with built-in or split wedge friction damping). High frequency response (up to 3000Hz) due to impact load can be fully simulated without any aliasing. Track substructure (sleeper, fastener, ballast and subgrade) can be fully modeled and simplified if required. In simplified cases (mainly track substructure), all simulated results by the developed model can fully agree with those of commercial software package such as Vampire Pro.
- Investigate the impact loading spectrum between wheel and rail caused by uneven longitudinal profiles at rail welds.
- Investigate the effect of vehicle speed, wavelength, irregularity depth and the position of the welded joint in a sleeper span.
- Optimize the design of rail profile and wheel profile for tangent and high degree curve tracks.
- Optimize the layout design of turnouts and variable rail profiles along the turnout.
- Predict rail wear level and optimize the grinding cycle and management scheme.

Expected outcomes

The proposed program focuses on mechanical aspects of vehicle-track interaction (and hence wheel-rail contact) and may therefore suit a project for one or two PhD students from mechanical engineering.

The following program of work is envisaged:

- Familiarization with wheel/rail contact conditions and material damage modes, including those associated with transient behavior at the wheel/rail interface.
- Familiarization with existing analytical techniques used for the examination of vehicle/track interaction, including derivation of wheel/rail contact conditions.
- Familiarization with the usage of commercial vehicle simulation software package, Vampire Pro.
- Wheel/rail contact data generation based on Kalker's rolling contact theory.
- Build 3D dynamic model for 3-piece ore cars with built-in or split wedge friction damping and 3D model for track structures (rails, sleepers, fasteners, ballasts, sub-grades, etc).
- Code computer programs using FORTRAN 90 for calculation and MATLAB for plotting and control purposes. Computed/simulated results should fully agree with commercial software package (Vampire Pro) when track substructure is simplified.
- Investigate alternative analytical approaches that could be applied to the examination of transient behavior of the wheel-rail interface (eg vertical or torsional oscillation within individual wheelsets, possible in combination with track geometry variations).
- Conduct simulations to examine transient behavior at the wheel/rail interface as a function of a representative range of influence factors.

- Investigate rail profile and wheel profile for balance between guidance and hunting-free. Optimize the profile design for least wear index and energy dissipation.
- Investigate the impact load when vehicle passing through a turnout (the variation in rail profile, track stiffness and track inertia along the turnout, contact between the back of the wheel flange and the check rail are considered).
- Optimize the layout design of turnouts and rail profiles along the turnouts.
- Predict rail wear level and optimize the grinding cycle and management scheme
- Journal paper/conference paper writing.