Computer Simulations of a Wagon Excitation on a Test Stand

Pavel POLACH, Michal HAJŽMAN

Section of Materials and Mechanical Engineering Research
ŠKODA VÝZKUM s.r.o.
Plzeň, Czech Republic

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Talk outline

1. Aims and motivation
2. UK HAA coal wagon description
3. Experimental measurements on a test stand
4. Multibody models of coal wagon in SIMPACK
5. Comparison of numerical simulations and experimental results
6. Problems of leaf springs modelling
7. Summary of sensitivity analysis and numerical experiments
8. Conclusions and outlook
Aims and motivation

• Measurements of the dynamical response of the two-axle coal wagon, type HAA, on a test stand (Footprint Eureka project)

• Two types of leaf springs can be used in suspensions – original steel UIC parabolic five-leaf springs and composite (glass reinforced plastic, GPR) two-leaf springs

• Simulations of the coal wagon, type HAA, behaviour on a test stand using the multibody model in SIMPACK software

• Tuning of the HAA coal wagon multibody model for the simulation of other laboratory tests aiming at using the multibody model for the simulation of drives along the railway track
UK HAA coal wagon description

- The wagon was tested in four loading states
- The loading was realized using concrete panels

<table>
<thead>
<tr>
<th>Load Level</th>
<th>Wagon loading [kg]</th>
<th>Load level mass</th>
<th>Whole added mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tare</td>
<td>467.3</td>
<td>467.3</td>
<td></td>
</tr>
<tr>
<td>Loading level 1</td>
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<td>9345.9</td>
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<tr>
<td>Loading level 2</td>
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<tr>
<td>Loading level 3</td>
<td>8280</td>
<td>26340.0</td>
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</tbody>
</table>
UK HAA coal wagon description

Steel parabolic five-leaf spring

Composite two-leaf spring
UK HAA coal wagon description

Wagon description

Spring characteristics
Experimental measurements on a test stand

• The shaker rig was assembled using the Schenck 4000 clamping and support system with additionally manufactured parts to have the possibility of exciting each wagon wheel

• Two Schenck PL 400 kN hydropuls actuators with two-step valves were situated under both wheels at rear axle, two Schenck PL 630 kN hydropuls actuators with three-step valves were situated under both wheels at front axle
Experimental measurements on a test stand

- The wagons wheels were placed with its flanges on short steel beams, with no permission of its movement in longitudinal direction
- The wheels were unbraked
- The actuators were controlled with the Schenck control unit S-59 with control programs individually prepared for each test
Experimental measurements on a test stand

Scheme of the installation of the wagon on a test stand and distribution of the measuring sensors

vyzkum@skoda.cz
Experimental measurements on a test stand

Measured quantities

- Relative displacement between the wheel and the wagon chassis (DS)
- Displacement of each actuator (DW)
- Force acting between the wheel and the shaker rig (LW)
- Acceleration of the hydraulic actuator (VAP)
- Acceleration of the wheel directly at the contact point with the shaker rig (VAW)
- Acceleration of front axle central point (VAA)
- Acceleration of the chassis at a steel beam directly over each wheel (VACH)
- Acceleration of the chassis at a steel beam at both sidewalls (BACH)
Experimental measurements on a test stand

Sweep tests

• The frequency sweep test in the range from 0 Hz to 30 Hz was carried out, which enabled to identify all of the significant resonance peaks including the sprung and unsprung mass peaks and body modes of the vehicle and their associated amplitude.

• During the sweep test, the actuators of the front axle were excited by a sinusoidal signal with constant amplitude of 0.5 mm or 1 mm.

• The frequency of the harmonic actuator oscillation was varied with the velocity 0.2 Hz/s.

• Two kinds of sweep tests were carried out: **bump test** (the actuators were excited in phase) and **roll test** (out of phase - at phase difference equal to 180°).
Experimental measurements on a test stand

Cyclic top test (CTT)

• CTT involves the simulation of a typical rail dip ranging between 6 mm and 12 mm at a particular location on both rails

• It is supposed that dip higher than 12 mm could cause the wagon derailment on the real track

• Actuators of the front axle were excited in a sinusoidal way in phase

• Frequency of these drops was swept from 0.5 Hz to 7 Hz to simulate a variation of speed of the vehicle running over the dips depending on the rail length

• CTT were carried out only with the empty wagon at tare load
Multibody models of coal wagon in SIMPACK

Visualization of the empty HAA coal wagon in SIMPACK software
Multibody models of coal wagon in SIMPACK

- It is possible to consider steel parabolic five-leaf springs or composite two-leaf springs in multibody models.
- Multibody models of all the wagon loading states were created.
- The multibody models are applicable in the simulations of laboratory exciting on a test stand (sophisticated wheel-rail contact models are not used).
- It is possible to simulate all the documented sweep and CTT tests, which were carried out during the laboratory measurements, with the multibody models.
- The wagon multibody models are relatively simple: they have ten degrees of freedom, they are formed by three bodies (front axle, rear axle and wagon body) connected by three kinematic joints.
- Data needed for the wagon multibody models creation were taken from the technical documentation or were assessed applying the users programs.
Comparison of numerical simulations and experimental results

- Relative displacement between the front left wheel and the wagon chassis, the empty wagon, composite two-leaf springs, sweep, bump 0.5 mm
Comparison of numerical simulations and experimental results

- Relative displacements between the front left and the rear left wheels and the wagon chassis, the empty wagon, steel parabolic five-leaf springs, sweep, bump 1mm, measured damping of the leaf springs.

Measured displacements

Calculated displacements
Comparison of numerical simulations and experimental results

- Relative displacements between the front left and the rear left wheels and the wagon chassis, the empty wagon, steel parabolic five-leaf springs, sweep, bump 1mm, improved damping of leaf springs

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Measured displacements

Calculated displacements
Problems of leaf springs modelling

- Measured stiffness characteristics assessed during the static vertical loading were considered in leaf springs modelling.
- Hysteresis of the measured stiffness characteristics of the leaf springs is not considered in multibody models, average characteristics are considered.
- It is evident from the steel parabolic five-leaf springs design, that friction forces, magnitudes of which were not experimentally determined, act between the individual leaves in the course of the springs deforming.
- If experimentally determined vertical damping coefficients of the steel parabolic five-leaf springs are considered in the multibody models, greater relative displacements between the wheels and the wagon chassis are observed during the simulations than during the laboratory testing.
- In order to create the multibody models it is necessary to carry out more complex assessment of the leaf springs characteristics.
Summary of sensitivity analysis and numerical experiments

• It is evident from the carried out verifying calculations with the HAA coal wagon multibody models that deviations between the calculated and experimentally determined monitored quantities are caused by the ignorance of all the needed leaf springs parameters

• Inertial characteristics of bodies and the characteristics used for modelling the wheel-shaker rig contact affect the simulations results substantially less

• When specifying the wagon model more precisely it will be necessary to pay attention especially to the leaf springs model and to the more thorough determination of needed characteristics of those springs
Conclusions and outlook

• The first approach of multibody models of HAA coal wagon to the real system was presented

• After defining the leaf springs model more precisely the multibody models are supposed to be extended by wheel-rail contact sophisticated models, to be possible to simulate experimental measurement, which was carried out at wagon pulling by a fork lift truck on the real rails, and planned experimental measurements at wagon pulling by locomotive

• The paper has originated in the framework of solving the project of the Ministry of Education, Youth and Sports of the Czech Republic 1M0519 „Research Centre of Rail Vehicles“