Simulation of a Narrow Gauge Vehicle using SIMPACK, Model Validation using Scaled Prototypes on Roller-Rig

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Introduction

• This work describe a research activity developed by Politecnico di Torino and Blue Engineering s.r.l. with the contribution of the Piemonte Region.
• Design of new railway vehicles requires complex investigations to achieve the desired dynamic performances (stability, Comfort, safety) and to verify structural strength.
• Dynamic simulations are often made using Multibody Codes, while FEM is used for structural analysis.
• Unfortunately experimental verification are only possible when the vehicle is almost completely designed and a prototype is tested on the track.
• This means that only small variation can be introduced depending on tests results.
Aim of the work

• Aim of the work was to improve the design methodology by using tests on scaled prototypes in order to validate the numerical models during the design phase of the bogie.

• The tests are also used to optimize the vehicle performance, analyzing the effect of variation on the suspension characteristics.
Method

• The method was applied to the design of a new vehicle carried on by Blue Engineering for a narrow gauge Italian line (Circum Vesuviana).

• The scaled prototypes have been realized by Politecnico di Torino and tested on a Roller Rig.

• Numerical simulations are performed using Simpack.
Vehicle Description

• The vehicle is designed to operate on a narrow gauge (950 mm) Italian line (CircumVesuviana).
• It is composed by three coach in fixed composition with two Jacobs bogie (center) and two standard bogie (external).
• Traction is distributed on only three bogies, the external bogie and one of the Jacobs.
• Design speed is 120 Km/h.
• Axle load is 12.5 tonnes (Maximum design load).
Vehicle Description

- The Primary suspension has been realized using rubber elements, with different stiffness in vertical and longitudinal direction.

- The bogie is made up of two frames, joined by two spherical bearings in order to reduce the torsional stiffness.

- The wheelset spacing is 2.1 m and the wheel radius is 380 mm (new).
Vehicle Description

- The secondary suspension is composed by two air-springs (R70) and two traction rod.
- Lateral movement is limited by a lateral bumpstop with a clearance of 10 mm.
- No anti roll-bar is used.
- The bolster is connected to the coach using a centre bearing.
- Viscous Damper are used for the vertical and lateral directions.
• The Numerical model of the vehicle was realised using Simpack 8.704

The model is composed by:

- 3 Coach.
- 4 Bogie (3 Motorized)
- The middle coach is supported by 2 Jacobs bogie and connected to the other coaches with non linear spring dampers placed on the roof.
Numerical Model

- A detailed model of the bogies was realized including:
  - Primary suspension
    - Linear stiffness to simulate rubber elements
  - Secondary suspension
    - Air Spring
    - Non linear bumpstop
    - Traction rod (linear stiffness)
    - Dampers: non linear characteristic.
    - Rigid constraint for the spherical joints on the bogie frame.
  - Traction
    - Non Linear traction motor characteristic.
    - Rigid gearbox
    - Elastic Motor-Gearbox connection
    - Elastic Motor-bogie and Gearbox frame connections.
Numerical simulations are performed in order to verify:

- Vehicle stability (Transient simulations)
- Curving performance (Y/Q, Y Forces)
- Slant capability (dQ/Q)
- Passenger Comfort (Ride Index)
Stability Analysis

- Primary suspension stiffness $C_x$ and $C_y$, has been designed evaluating the critical speed.
- The analysis has been carried out using linear and non-linear profiles.

Limit Cycles
Curve Analysis

- The analysis have been carried using different curves radius.
- The evaluated parameters in particular: $Y/Q$, ripage forces (according to UIC518) and primary suspension displacements.

Example R=180 m
$Y/Q < 0.5$
Curve Analysis

• The analysis have been carried using different curves radius.
• The evaluated parameters in particular: Y/Q, ripge forces (according to UIC518) and primary suspension displacements.

Y Forces < 14000 N
UIC Limit = 32000 N
Curve Analysis

Lateral Bumstop Optimization

- Lateral bumstops have been designed according to the evaluation of lateral coach displacements.
Comfort Analysis

- Gauge and vertical irregularities are simulated on track using non linear stochastic by polynomials (low and high ORE excitations).
- The comfort values are calculated according to UNI12299 and standard ISO2631.
- Lateral anti-roll dumpers between coach are designed according to the comfort analysis results.
• Gauge and vertical irregularities are simulated on track using non-linear stochastic by polynomials (low and high ORE excitations).

• The comfort values are calculated according to UNI12299 and standard ISO2631.

• Lateral anti-roll dumpers between coach are designed according to the comfort analysis results.
• The calculation has been developed according to ORE B55.

• Q forces, primary and secondary suspensions stage displacements and anti-roll spring behaviour has been evaluated.
Slant Analysis

**Q Forces**

\[ \frac{dQ}{Q} < 30\% \]

Forces and displacements on the roof connection
• Design of the new bogie was supported both with numerical simulations and experimental test on Roller-Rig.
• Tests were performed on scaled prototypes (1:4, 1:3.5) realized using a dynamic similitude approach proposed by Jaschinski.
• Experiments were performed in two phases:
  1) During the pre-design stage of the project a modular bogie was used to achieve the first validation (stability).
  2) Once the design of the bogie was completed, a 1:4 accurate prototype has been designed and realized in order to perform final tests (Stability-Comfort-Braking).
Prototype description

**Modular prototype:**
This bogie was designed to test vehicles with the standard European Gauges (1435 mm) in 1:5 scale.

Since the gauge could not be changed easily, tests were performed with a smaller (1:3.3) scale in order to reproduce the narrow gauge (1000 mm).

Inerzias (Tare only), geometry and stiffness were dynamically scaled in order to perform stability analysis.

Some limitation are related to:
- Bogie frame in 1 piece
- Linear profiles
Prototype description

FINAL PROTOTYPE:
Has been realized in order to reproduce the real vehicle with special care to:

- Suspension stiffnesses
- Geometry
- Inertia

- The bogie frame was realized in two separate sides with spherical bearing connection.
- Air springs were used for the secondary suspensions
- Scaled Non linear profiles for wheel and rail.
Both prototypes were used to validate numerical results.

- Identification of the model was performed with Experimental Modal Analysis and tests on the components.
- Numerical model and prototypes were modified to achieve a good agreement for stiffness and Inertia.
Experimental tests were performed in order to:

1) Simulate the slant Behaviour (Static)
2) Simulate the slant Behaviour (dynamic) acting on the primary suspension.
3) Simulate the running stability.
4) Evaluate the vertical response of the vehicle to track (rollers) irregularities (Comfort)
Test on Prototype

Vertical accelerations: bogie, coach, wheelset.

Vertical Response to rollers irregularities
Conclusion

- The combination of Multibody Numerical Simulations (Simpack) and Experimental tests on scaled prototypes was used in order to improve the design phase of a new vehicle.
- This method allows to verify the design and simulation results earlier in the Project timeline.
- Earlier detection of errors and problems reduces costs and design time.
- Validation made with scaled models can not be considered as a validation performed “on the real vehicle”: test on track are always required, but is useful to improve models and to perform parametric optimizations.
Conclusion