Comparison of Simulation and Measurements

The rail vehicle approval process today is costly and time-consuming. "Virtual testing" using multi-body simulations is one approach to reduce these costs. During the European research project DynoTRAIN, one of the main activities in work package 5 was the comparison of simulations and measurements from on-track tests to develop the process and criteria for model validation. The on-track measurements were carried out with a measurement train in Germany, France, Switzerland and Italy. This article describes some selected simulations with the Bim 547.5 coach using the simulation tool SIMPACK, which have been carried out by Bombardier Transportation.

INTRODUCTION

For the past two decades, Europe has increased its cross-border transport of freight and passengers. The European Union is aware that this makes cross-border rail transport a viable alternative to road transport. Historically, every country in Europe developed its own railway system with different national rules for testing the acceptability of railway vehicles’ running characteristics. Today, it is necessary for cross-border rail transport to be interoperable with various railway systems. The European approach to interoperability led to two European Commission (EC) Council Directives: 96/48/EC on July 23, 1996 on the interoperability of trans-European high-speed rail systems and 2001/16/EC on March 19, 2001 on the interoperability of the conventional rail systems. At both of these councils, processes to determine standard rail vehicle approval were established. Today, testing vehicle running characteristics is a costly and time-consuming process since the vehicle certification against European standards (EN), like EN 14363 [1], requires multiple field tests. Unexpected environmental or other boundary conditions influence the results so that field tests have to be repeated several times in order to cover the possible range of circumstances, increasing costs and duration of vehicle approval. One approach to reduce this effort could be "virtual testing" using numerical multi-body simulations (MBS). For the application of this methodology, the validation of the simulation model is essential.

"Today, it is necessary for cross-border rail transport to be interoperable with various railway systems."

Fig. 1a: MD36 bogie of a Bim 547.5 coach
from On-Track Tests for Model Validation

THE DYNOTRAIN PROJECT
In 2007, the European Commission (EC) initialized the Seventh Framework Programme (FP7) for research and technological development. DynoTRAIN was one of three projects in the TrioTRAIN cluster (Total Regulatory Acceptance Interoperable Network), started in June 2009 (scheduled project duration: 48 months, extended to 52 months) with funding by the EC under FP7 (Grant Agreement no. 234079) with a budget of € 3.3 million. DynoTRAIN included the following objectives: closing of open points in the high speed (HS) and conventional rail (CR) technical specifications for interoperability (TSIs) related to vehicle dynamics; harmonize European and national standards on railway dynamics; and reduce costs of certification and development of an innovative certification process using computer simulations. The research work was divided into seven work packages (WP):

WP1: Measurement of track geometry quality and virtual certification
WP2: Track geometry quality
WP3: Contact geometry
WP4: Track loading limits related to network access
WP5: Model building and validation
WP6: Virtual certification of modified vehicles and vehicles running in other conditions
WP7: Regulatory acceptance

The DynoTRAIN project team is a unique international consortium co-ordinated by UNIFE, the European Rail Industry. In WP5, 14 partners from industry (Bombardier, Siemens, Alstom, CAF, AnsaldoBreda), universities, public research institutes (TUB, KTH, POLIMI, IFSTTAR, CEIT, RSSB) and transport companies (DB, Trenitalia, SNCF) collaborate. For more information, see www.triotrain.eu.

DYNOTRAIN MEASUREMENT CAMPAIGN
In October 2010, the German transport company Deutsche Bahn (DB) compiled a 325 m long measurement train. Over a four-week period, on-track measurements were carried out with slightly different train configurations over a 5000 km distance through Germany, France, Switzerland and Italy. The measurement train consisted of 13 different rail vehicles:

- One electric locomotive DB series 120.1 (normal operation mode, with measuring equipment)
- One inter-city passenger coach series Bim 547.5 (normal operation mode, empty, with measuring equipment)
- Two flat freight wagons with Y25 bogies for containers and swap bodies series Sgns 691 (one wagon empty, one wagon laden, wheelset load of 22.5 t, both with measuring equipment)
- Freight wagon unit consisting of two flat wagons with stakes series Laas (one wagon empty, one wagon laden, wheelset load of 20.0 t, both with measuring equipment)
CUSTOMER APPLICATION | Gernoth Götz, Bombardier Transportation GmbH

Fig. 2: Wheel loads first wheelset, line Biasca – Göschelen, curve radius 278 m, velocity 74 km/h, superelevation 150 mm

- One DB RAILab coach (DB Rolling Analysis and Inspection Laboratory for the measurement of track geometry, track irregularities and rail profiles)
- One measuring coach with equipment for data recording of locomotive, passenger and freight coaches
- Six brake coaches

During the test campaign, the vehicle dynamics of the locomotive, the passenger and the freight coaches were measured using the following measurement equipment:

- Instrumented wheelsets to measure the rail-wheel contact forces Y (lateral force), Q (vertical force) and Tx (longitudinal force)
- Acceleration sensors to measure the vertical and lateral accelerations of axle boxes, bogie frames and car body
- Displacement sensors to measure the relative displacements in the primary and secondary suspension.

At each vehicle, around 50 measuring channels were recorded with a maximum sampling rate of 1200 Hz depending on the recorded quantity. The recorded data provided the data basis for a comparison of measurement and simulation in DynoTRAIN WP5.

**BIM 547.5 SIMULATION MODEL**

The Bim 547.5 passenger coach is part of the standard UIC-X wagon series that DB has used since 1952 in D-trains and inter-city trains. Bombardier Transportation simulated this passenger coach with SIMPACK using technical drawings and data sheets (Fig. 1). The initial model consisted of one car body and two bogie series Minden Deutz 36 (MD36). All mass bodies were modeled as rigid bodies. The bogie contained conventional wheelsets, axle guides for wheelset guidance, flexicoil springs for primary and secondary suspension and dampers in different spatial directions. In comparison to freight wagons, the passenger coaches have for ride comfort reasons a secondary suspension level (MD36: bogie bolster with flexicoil springs). Friction forces occur between the bogie bolster and the car body and also in the secondary spring support. The vehicle has a maximum velocity of 200 km/h, a wheelset base distance of 2.5 m, a bogie base distance of 19.0 m and a wheel diameter of 0.95 m.

**DYNOTRAIN WP5 SIMULATIONS**

One of the main activities in WP5 was the comparison of simulation and measurements from on-track tests to develop the process and criteria for model validation. The importance of boundary conditions (measured wheel and rail profiles, measured track irregularities) [2] and model improvements by stationary tests were also investigated. 17 track sections representing...
all four test zones according to EN 14363 [1] were defined to carry out the comparisons with the on-track tests. Furthermore, different groups of stationary tests were defined to compare their results with simulations. The sequence of the simulation activity was as follows: initially, the simulation model based on technical drawings and data sheets was only compared with on-track tests in straight sections with a check on the wheel loads (to adjust the car body mass properties), but without comparison to stationary tests. To analyze the effect of measured boundary conditions, the simulation results, based on different combinations of measured and standard boundary conditions, were compared to the on-track measurements. In the next step, the simulation model was compared to defined stationary test groups. If possible, the simulation model was improved to reduce the difference between simulation and measurement of stationary tests. Subsequently the same on-track comparisons had been carried out again. The purpose of the simulation activity was to highlight differences between simulation and measurements in the Q-forces were slightly reduced. This was mainly dependent on the adjustment of the height of the car body center of gravity.

Fig. 3 shows exemplary comparisons with stationary tests on the results of the bogie rotation test. The main difference between the initial simulated and measured torque hysteresis curves can be observed for rotation angles between ±4 and ±4.5 degrees. In the initial simulation model, the characteristic of the secondary longitudinal bump stop between the bogie frame and bolster includes a free play. This characteristic was estimated and represented an uncertain model parameter. The approach used to improve the simulation model was a reduction of this free play to zero and a new bump stop characteristic. The comparison of the improved model demonstrates very good agreement between simulation and measurement.

CONCLUSION

The complete analysis of the simulation results of all vehicles and the proposed process and criteria for model validation has been published in the final WP5 deliverable and at conferences IAVSD 2013 in Qingdao, China [3] and Bogie ‘13 in Budapest, Hungary [4]. Based on the proposed validation methodology in WP5, the Bim 547.5 vehicle model fulfils the validation limits and can therefore be regarded as validated. The vehicle model is ready to use for virtual vehicle approval. The following conclusions can be drawn regarding the comparisons between simulation and measurements:

- Measured track irregularities as well as measured rail and wheel profiles improve the accuracy of simulation results compared to on-track measurements.
- Stationary tests can be used for model improvements if there are uncertain vehicle parameters. Due to a good data basis for the Bim 547.5 coach, the vehicle model improvement by comparisons with stationary tests was only marginal; the main improvement was achieved by comparisons with on-track test measurements.

REFERENCES


Fig. 3: Bogie rotation test results in comparison with simulation using initial vehicle model and model after adjustment

“To analyze the effect of measured boundary conditions, the simulation results, were compared to the on-track measurements.”

By using the final adjusted model, the quasi-static differences between simulation and measurements in the Q-forces were slightly reduced. This was mainly dependent on the adjustment of the height of the car body center of gravity.