Roller Rig Experiments with a Mechatronic Railway Bogie

Systems based on active elements and feedback control offer superior properties over passive solutions and are increasingly being utilized across all transport systems.

Due to high demands on reliability and safety, as well as many other reasons, active control is rarely used at the wheelset guidance in a bogie of a railway vehicle. However, active control is still a favorable solution because of the many necessary compromises that have to be made in the classic passive approach of railway bogie design.

This article deals with a 2-axle railway bogie with independently rotating wheels (IRW) and active wheelset guidance and its practical implementation as a 1/3.5 scaled model on a roller rig. The main goal is to perform multi-body software (MBS) simulations and scaled roller rig experiments in order to verify and demonstrate the possibilities of active wheelset control.

INTRODUCTION

MBS simulations play an important role in the development of rail vehicles and have steadily increasing significance. Although results of today's MBS simulation are very realistic, experimental verification is still unavoidable. Track tests play an essential role in the process of the of new rolling stock approval. But the track tests are also very expensive, time consuming and difficult to organize. Therefore, it is almost impossible to perform them in a university environment. Moreover, the track tests are not suitable for initial experiments with completely new concepts of running gears, because in that case, it is impossible to fulfill all safety requirements.

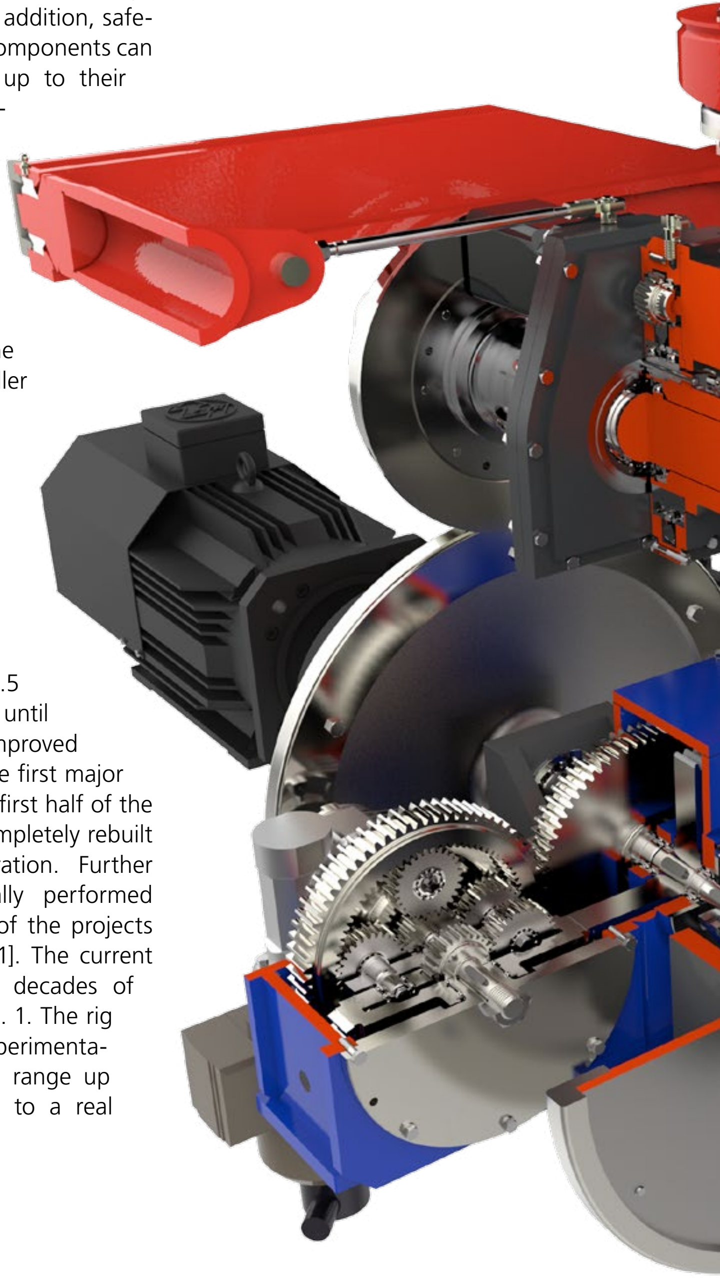
> *"…the use of a roller rig for verifying MBS simulations of entirely new running gear concepts is very advantageous…"*

Fig. 1: CTU roller rig

In contrast to track tests, roller rigs, and especially scaled roller rigs, offer the advantages of low cost, low spatial demands, a safe and controlled laboratory environment, and ease of access to components and test apparatus. In addition, safety critical components can be tested up to their limits without the risk of a railway accident [2]. Due to the above reasons, the use of a roller rig for verifying MBS simulations of entirely new running gear concepts is very advantageous, even though the behavior of the vehicle on roller rig is not identical to the behavior on the track.

CTU ROLLER RIG

The history of roller rig testing at the CTU began in the late 1980's, when the first single axis roller rig was built. The scale of the first CTU roller rig was 1/3.5 and remained unchanged until now. The rig had been improved and updated many times. The first major adjustment came during the first half of the 1990's, when the rig was completely rebuilt to a 2-axle type configuration. Further adjustments were specifically performed according to the objectives of the projects in which the rig was used [1]. The current state of the rig after two decades of modifications is shown in Fig. 1. The rig is designed to carry out experimentation with a roller revolution range up to 700 min^{-1}, corresponding to a real vehicle speed of 230 km/h. The CTU roller rig is not restricted to perform experiments only on a straight track, but it is also capable of simulating the negotiation of curved track, or track consisting of an arbitrary



number of straight, transition and constant curvature sections.

The CTU roller rig is equipped with an experimental two-axle bogie. The bogie wheelbase is 714 mm, the track gauge is 410 mm and the wheel diameter is 263 mm. This corresponds to a wheelbase of 2500 mm and 920 mm wheel diameter of real standard gauged vehicle. The two-axle bogie has no vertical primary suspension. It is equipped with wheelsets that can easily be setup for conventional or IRW wheelset type. Wheel profiles with different taper grades ranging from 1/40 to 1/5 are available.

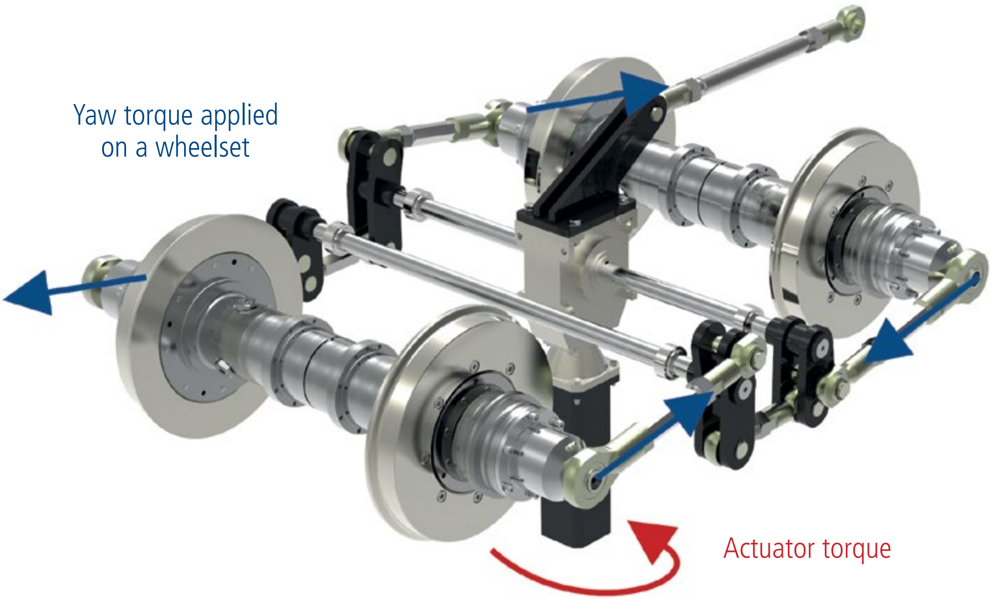
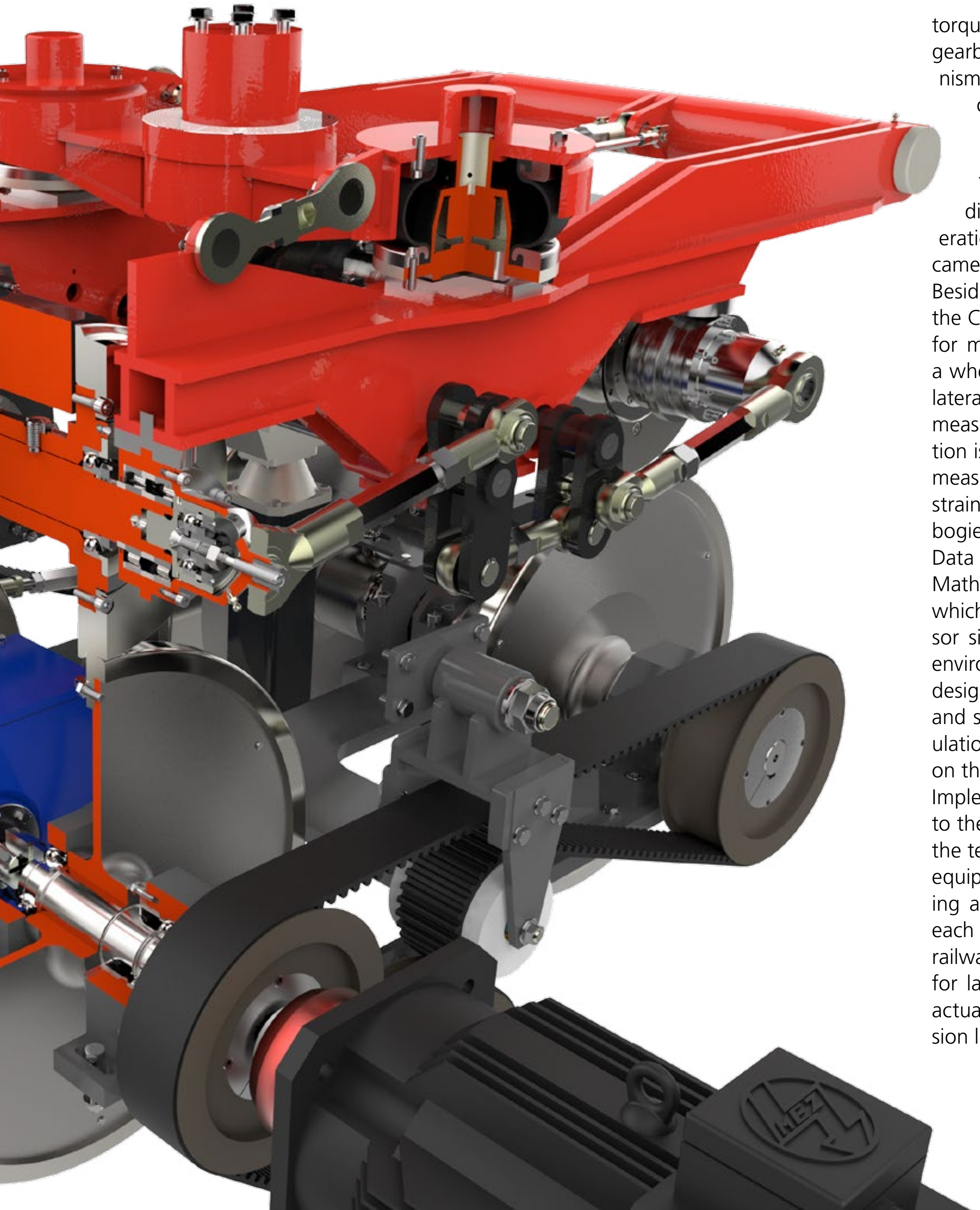


Fig. 2: Single actuator configuration of the wheelset steering mechanism

The wheelsets are guided by an actively controlled steering mechanism [3]. The actuator can be controlled to a desired magnitude of yaw torque acting on the wheelset, or to a desired value of yaw angle between wheelset and bogie frame. The actuator torque is transmitted to wheelset via bevel gearbox and linkages (Fig. 2). The mechanism is designed so that it is possible to use one actuator for the whole bogie, or to have two actuators per bogie and control each wheelset independently.



The rig is equipped with contact displacement sensors, single axis acceleration sensors, load cells, encoders and a camera for observing wheel-roller contact. Besides those industrial standard sensors, the CTU roller rig is equipped with a system for measuring the forces in the contact of a wheel and roller. For the measurement of lateral wheel-roller forces, the principle of measurement of the wheel disc deformation is used as applied to the rollers. For the measurement of vertical wheel-roller forces strain, gauged beams between axle box and bogie frame are used.

Data acquisition is obtained using the MathWorks Real-Time Windows Target™, which enables realtime processing of sensor signals in the MATLAB® and Simulink® environment. This approach allows one to design a Simulink model of the controller and subsequently to use it for both co-simulation with an MBS model and experiment on the roller rig.

Implementation of individual wheel drives to the test bogie is the next planned step in the test bogie design (Fig. 3). The test bogie equipped with actuated wheelset steering and independently controlled drives of each wheel, represents a fully mechatronic railway bogie that provides the possibility for laboratory tests of the most applicable actuation schemes at the primary suspension level and the wheelset itself.

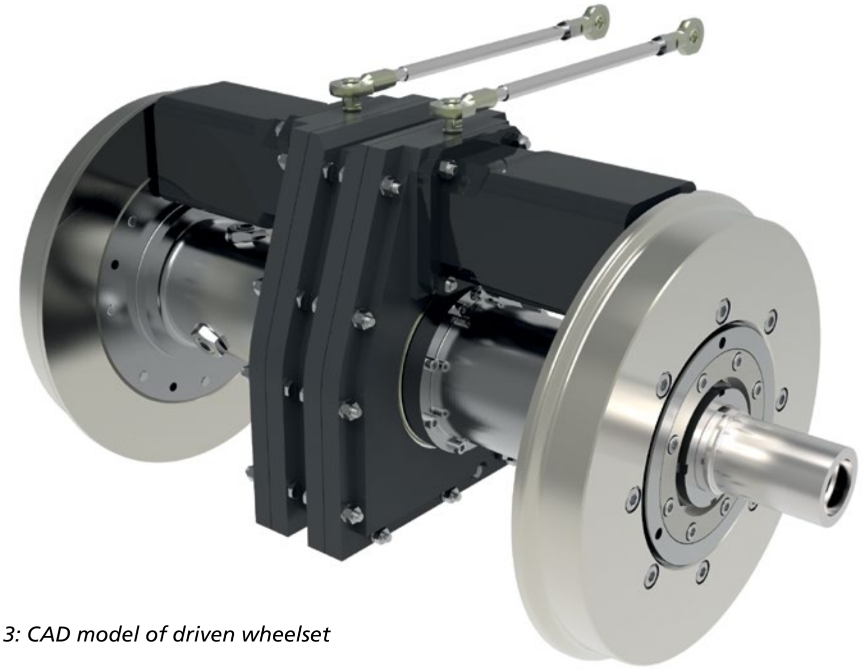


Fig. 3: CAD model of driven wheelset

MBS MODEL DESCRIPTION

SIMPACK 9.5 was used to build the MBS model of the experimental bogie on the CTU roller rig (Fig. 4). This model represents the CTU roller rig design at the planned final stage of development, when the bogie is equipped with independent yaw control of each wheelset and independently driven wheels. Like the real roller rig bogie, the MBS model can be configured to simulate IRW or conventional wheelsets or using one or two actuators for wheelset steering. This is done by enabling and disabling the designated Force Elements and Constraints.

> ***"...by using active control, it is possible to avoid flange contacts, as well as significantly reduce lateral wheel-rail forces."***

Traction blocks and wheelset steering actuators are built as separate models and inserted into the final model as a Substructure.

Control strategy for the torque of traction motors and torque or steering angle of wheelset steering actuators is modelled in the MATLAB and Simulink environment. The SIMAT interface is used to connect and co-simulate control strategy model and roller rig MBS model.

MBS SIMULATIONS RESULTS

Several goals for active wheelset control can be found. Improvement of IRW wheelset behavior will be shown as an example. Very good high speed stability with virtually no hunting oscillation, but also poor curving performance and self-centering ability of the IRW axels are well known. This can be demonstrated on a simple curve passing scenario. The track consists of a 100 m straight, 30 m transitions and a 50 m constant curvature section. Because lateral forces caused by curving cannot be accounted for by CTU roller rig, these centrifugal forces are assumed to be fully compensated for by using superelevation of rails. The curve radius is 86 m, which corresponds to 300 m at full scale. The bogie is perfectly aligned to the center of the track at the beginning of the simulation. Due to difference of vertical wheel-rail forces and wheel-rail contact angle, a lateral force is generated. Because, for a passive IRW bogie, there is no force that could compensate for it, the passive bogie moves laterally, even in the straight track, until steady state flange contact is reached. When the passive bogie enters the transition track, the bogie quickly moves to the outer rail. There are also force peaks when the flange hits the rail, as well as a high mean value of lateral wheel-rail force during steady state curving (Fig. 5 & 6, blue line).

To improve this behavior, active wheelset control is introduced. Each wheelset is equipped by a yaw actuator. Yaw angle between the wheelset and the bogie frame is controlled by a PI controller, which is fed by the lateral wheelset position. The control goal is to minimize lateral deviation of the wheelset towards the track center and thus minimize flange contacts.

Simulation with the same scenario as with the passive bogie was performed. Results (Fig. 5 and 6, red line) show that, by using active control, it is possible to avoid flange contacts, as well as significantly reduce lateral wheel-rail forces. Lateral wheel-rail force is virtually constant, and its magnitude is given by the lateral component of the normal force of the wheel-rail contact.

ROLLER RIG IMPLEMENTATION

The recent roller rig simulations were focused mainly on testing of roller rig capabilities in terms of simulation curved track negotiation and measurement of lateral wheel-rail forces. Measurements comparing the magnitude of the guiding forces of conventional and IRW bogie were performed at various track radii [4] (Fig. 7).

Position control of the wheelset steering mechanism has been tested as the next step. The bogie was setup with a conventional wheelset configuration, and wheelsets yaw angle, with respect to the bogie frame, was steered proportionally to the track curvature. Influence of wheelset steering angle to the lateral wheel-rail forces was observed [3].

Those tests confirmed the functionality of the wheelsets steering actuator and

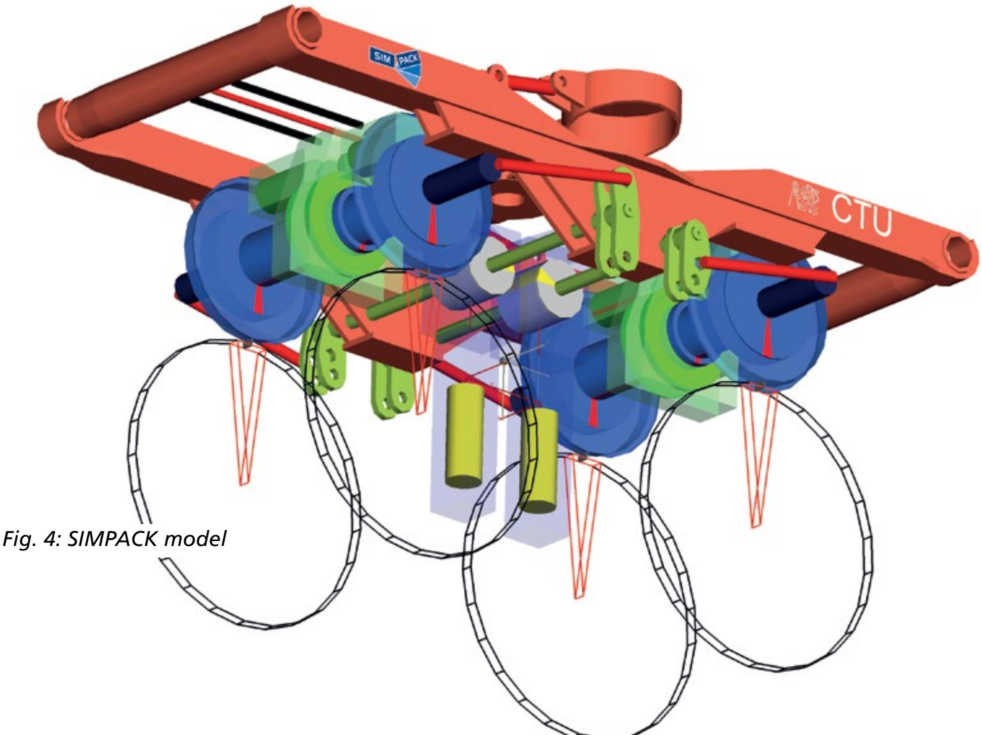


Fig. 4: SIMPACK model

mechanism and capability of lateral wheel rail forces measurement on the CTU roller rig. Roller rig tests to verify improvement of IRW axels with self-centering and guiding properties by active steering are planned for the first half of 2014.

SUMMARY AND FUTURE OUTLOOK

Although roller rigs cannot fully replace track tests, they are very useful for verifying running behavior of fundamentally new rolling gear concepts. The CTU scaled roller rig is developed to test running dynamics of a 2-axle bogie with active wheelset control. With the use of SIMPACK software, the MBS model of a railway bogie on the CTU roller rig was built. This model enables one to study a number of different wheelset actuation schemes. The first MBS simulations were focused on improvement of IRW axle self-centering and guiding properties by means of active steering in yaw direction. These simulations have provided a significant benefit to the active control in terms of improving the self-centering capability of the IRW axle and reduction of the guiding forces in curves.

Roller rig tests focused on verification of MBS simulation results are being prepared. The implementation of individual wheel drives to the roller rig bogie and MBS simulations focused on active control of individual wheel drives are planned for the near future.

ACKNOWLEDGEMENT

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REFERENCES

[1] P. Bauer, J. Kalivoda: Experimentální výzkum na kladkovém zkušebním stavu ČVUT, In: Nová železniní technika. 2006, Vol. 14, **no***. 2, pp. 15–19.*

[2] J. Gerlici, T. Lack, J. Harušinec: Realistic simulation of railway operation on the RAILBCOT test stand. In: Applied Mechanics and Materials, Vol. 486 (2014), pp. 387–395.

[3] J. Kalivoda, P. Bauer: "Roller Rig Implementation of Active Wheelset Steering", In "Proceedings of the First International Conference on Railway Technology: Research, Development and Maintenance", Civil-Comp Press, Stirlingshire, UK, Paper 63, 2012.

[4] J. Kalivoda, P. Bauer: "Curving Behaviour of 2-axle Bogie with Independently Rotating Wheels — Simulations and Scaled Roller Rig Tests", In. 23rd International Symposium on Dynamics of Vehicles on Roads and Tracks, Qing dao, China 2013.

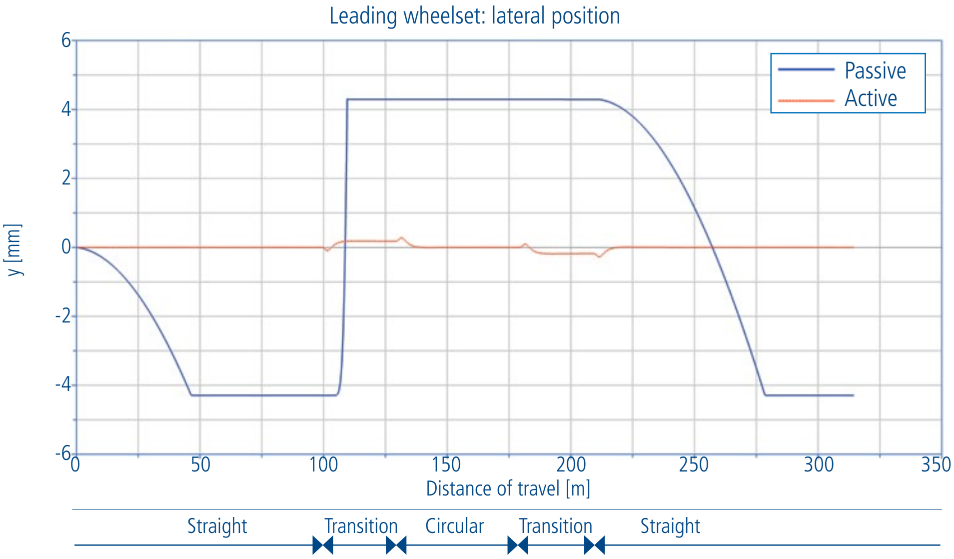

Fig. 5: Development of the lateral position of the leading wheelset (simulation)

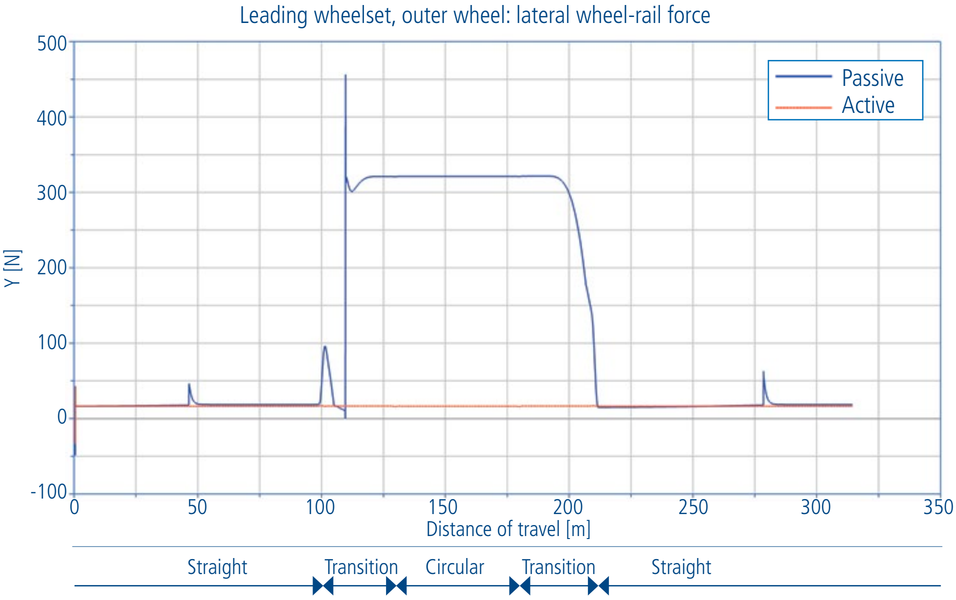

Fig. 6: Development of the lateral wheel–rail force (simulation)

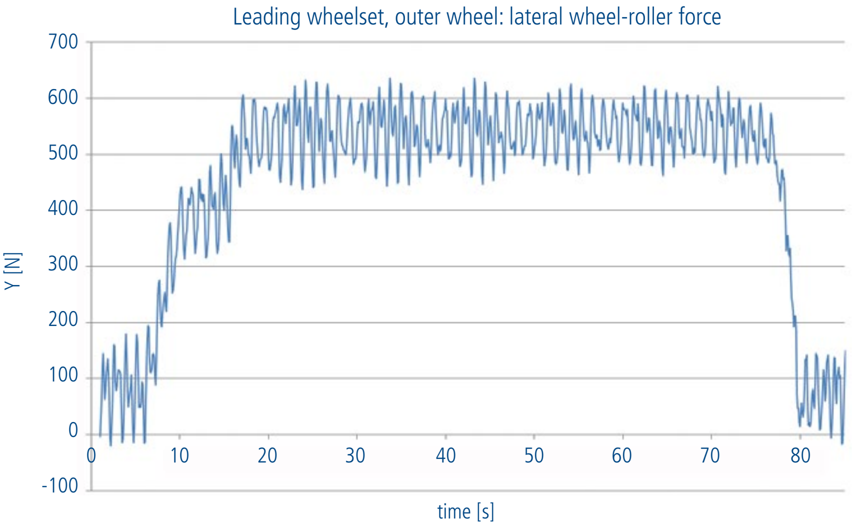

Fig. 7: Example of the roller rig measurement of the lateral wheel-rail force