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Measurement of wheel-rail contact forces at the experimental roller rig

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Abstract. The article describes the newly developed system for the measurement of the forces acting in wheel rail contacts, which have been implemented on an experimental scaled railway bogie. The bogie is utilized for roller rig experiments focused on active controlled wheelset guidance. The measuring system consists of three parts: measurement of the lateral component of wheel-rail contact force, measurement of axle-box forces and measurement of overall tractive effort. The lateral component of wheel-rail contact force is determined by a measurement of the transverse deformation of roller disks. In order to determine axle-box forces, one component of the wheelset guidance was specifically designed as a three axis load cell. The overall tractive effort is determined by measurement of forces in the mechanism that connects the experimental bogie and the roller rig mainframe. The paper describes in detail the design and first test of the system.

Introduction

Force interaction in between rails and railway wheels is one of the most important issues in the development of the new rolling stock. Todays' effort to build an economic and environment friendly railroad brings a general and sustained demand to reduce wheel-rail contact forces below legislative limits as much as possible. Conventional methods of reduction wheel-rail contact forces are based on the optimization of suspension characteristics [1], or on mechanic or hydraulic linkages between the various components of the running gear. Because the possibilities of conventional methods are increasingly encountered at their limits, ideas of the utilization of active controlled elements in the wheelset guidance and railway vehicle suspension occur [2, 3].

The mathematical simulations of running behaviour of railway vehicles possessing active controlled running gears give a very promising results [4]. However, prior to the application of such systems in practice, they need to be thoroughly tested to meet the requirements of safety and operational reliability. Roller rigs can be advantageously used for these tests, because they allow testing of vehicle running behaviour in laboratory conditions, where it is possible to simulate extreme situations without a risk of railway accident [5, 6]. The principle of roller rig is in the replacement of a track by rotating rollers with a rail profile on their circumference. The tested vehicle is longitudinally fixed. Nevertheless, the creep conditions and forces in the wheel-roller contact points are analogical to the conditions in wheel-rail contacts of a vehicle running in a real track.

At the CTU in Prague a 1:3.5 scaled roller rig possessing an experimental bogie is utilized (Fig. 1). Each wheelset of the experimental bogie is equipped with an actuated steering mechanism for applying of a controlled torque to the wheelset in the yaw direction, or to steer wheelset to desired magnitude of yaw angle between the wheelset and the bogie frame [7]. The rig serves as an experimental facility for verification of results of mathematical simulations and demonstration of benefits of active controlled elements in railway bogies [8].

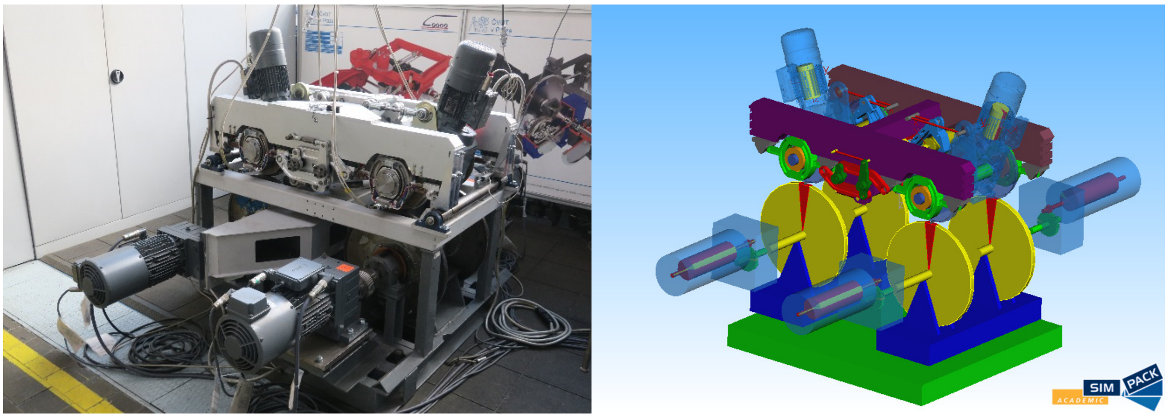

Fig. 1: The experimental railway bogie at the CTU roller rig (left) and its' MBS model (right)

An important operating parameter of rolling stock is the intensity the wear of wheels and rails. This wear is mainly affected by the magnitude of forces acting in wheel-rail contacts. Knowledge of these forces is therefore very important in assessing new types of railway running gears. However, a measurement of contact forces directly in the wheel-rail contact point is virtually impossible. In practice, indirect methods, usually based on the measurement of the strain on vehicle parts, are used [9, 10]. It is desirable to measure those strains as close as possible to the wheel-rail contact point.

Three systems of force measurement, which could be used for determination of wheel-rail contact forces are utilized at the CTU roller rig:

- measurement of the transverse deformation of roller disks,
- measurement of axle-box forces, i.e. forces transmitted between axle-boxes and the bogie-frame,
- measurement of bogie tractive effort, i.e. sum of longitudinal forces transmitted in the connection of the experimental bogie and the roller rig mainframe.

Measurement of the roller disc deformation

An important research tool in experimental testing of rail vehicles are strain gauge instrumented wheelsets, where the forces acting in the wheel-rail contacts are estimated by measurement of radial strains of wheel plates. In the case of the CTU roller rig a similar approach is used. Because the wheelsets of the experimental bogie are not applicable due to the small diameter and very high stiffness of the wheel disc, the system of measurement of disc strains was applied on the rollers (Fig. 2). This approach exhibits very good properties in terms of measuring the lateral component of wheel-rail contact forces. Its disadvantages are especially insufficiently low sensitivity for measurement of vertical and longitudinal components of wheel-rail contact forces and the necessity to transmit the output signal from rotating parts. At the CTU roller rig, several signal transmission systems were tested. Finally the own wireless signal transmission system has been developed in a cooperation with the CTU Faculty of Biomedical Engineering. The system provides synchronized wireless data transfer from all four roller in a sampling rate of 1 kHz and currently undergoes the final testing phase (fig 3).

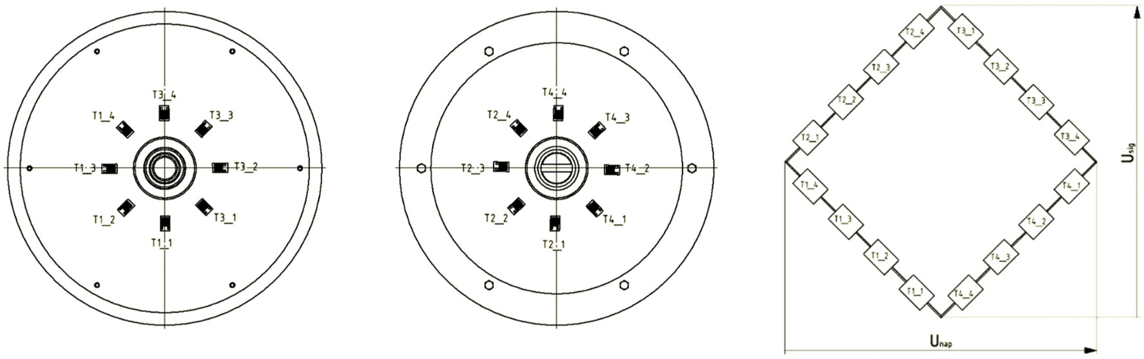

Fig. 2: Placement and connection of strain gauges

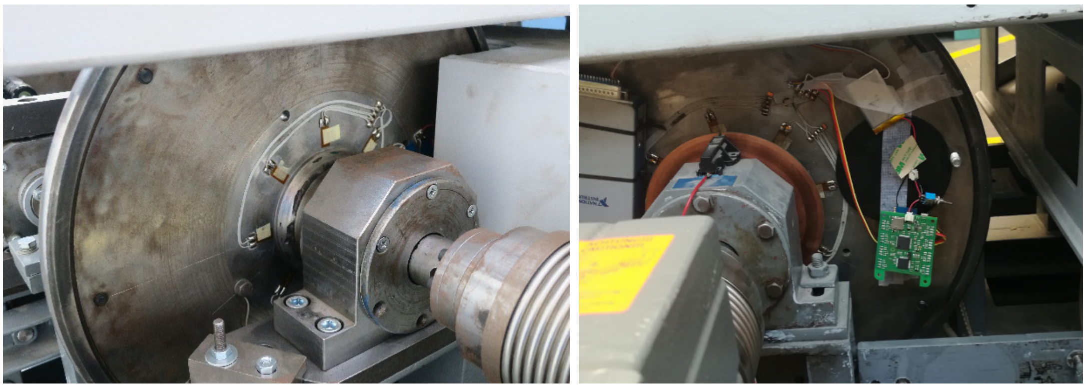

Fig. 3: Instrumented roller

Axle-box forces measurement

The possibility to measure wheel-rail contact forces was also considered in the design of the experimental bogie. In this case the contact forces are estimated by measurement of axle-box forces, i.e. forces transmitted between axle-boxes and the bogie frame. Considering several possible solutions, the development of specific component of the wheelset guidance acting as a 3-axis load cell was chosen. All forces between each axle-box and bogie frame are transmitted via a stirrup (Fig. 4), that is optimized for the strain gauge placement.

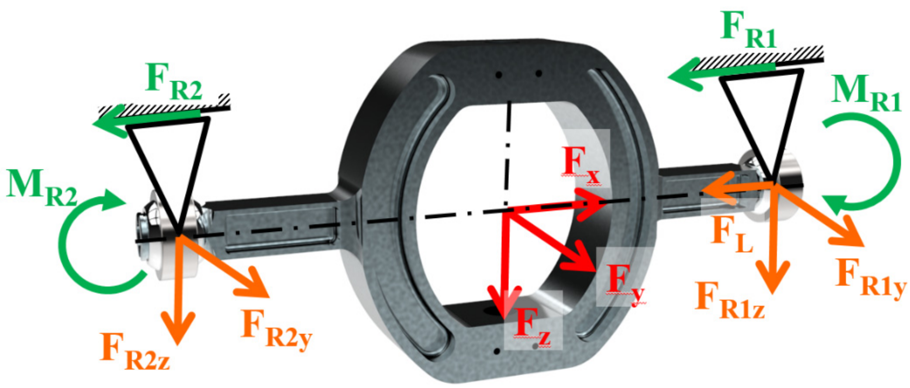

Fig. 4: Load cell for axle-box forces measurement

Each stirrup is instrumented with 36 strain gauges in three full bridges (Fig. 5). The wiring of strain gauges ensures the measurement of longitudinal F_x, lateral F_y and vertical F_z

component of axle-box force independently of each other. The parasitic resistive forces F_{R1}, F_{R2} and torques M_{R1}, M_{R2} in the connection of the stirrup and the bogie frame are eliminated from the measured signal [11].

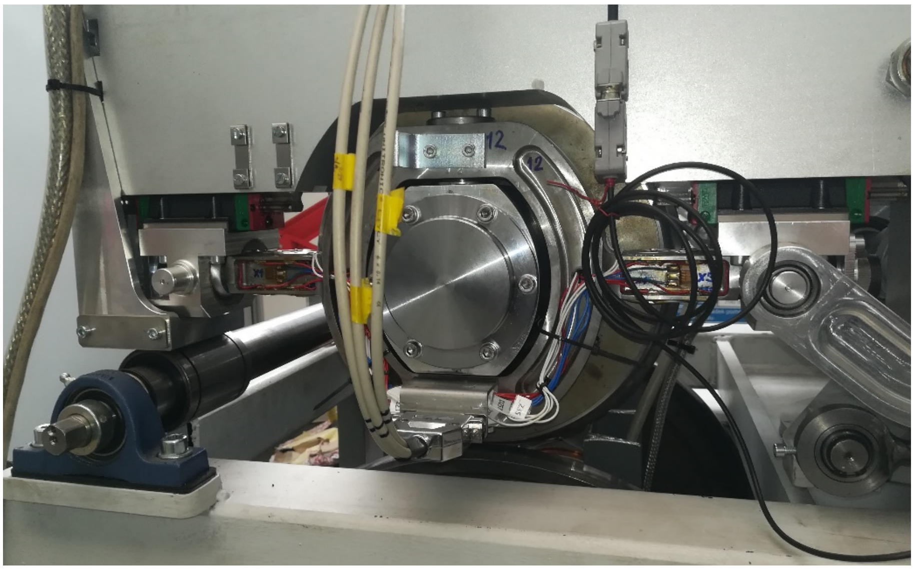

Fig. 5: Instrumented stirrup

Information on the magnitude of axle-box forces are not regarded as an adequate substitute for information about the value of wheel-rail contact forces. They differ due to the inertia of wheelset. Moreover, the distribution of wheel-rail contact forces between the right and left wheel could not be determined by measurement of axle-box forces. The advantage of the measurement of axle-box forces is its easy realization without the necessity to transmit a signal from rotating parts.

Measurement of bogie tractive effort

The bogie is connected to the roller rig main frame using a Watt's mechanism (Fig. 6). The arm "1" is connected to the roller rig mainframe by a pair of ball-bearings and rotates around vertical pivot in its' centre. The bogie is connected to the arm "1" by two short linkages "2".

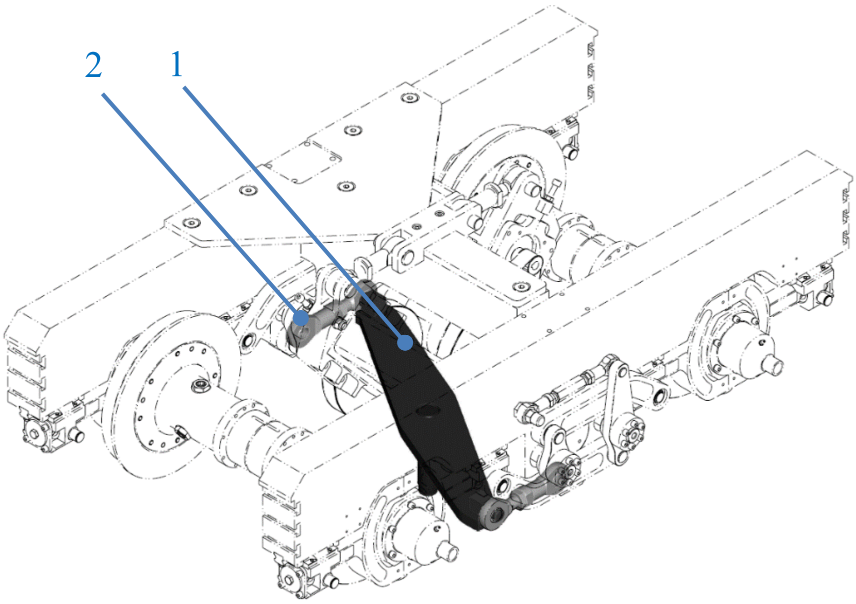

Fig. 6: The mechanism of connection between the bogie and the rig mainframe

Thus the bogie is longitudinally fixed with respect to the roller rig mainframe, whereas it can move in lateral and yaw direction without restrictions. The linkages "2" are instrumented with industrial single axis force transducer HBM U9B (Fig. 7) which measures tensile and compressive forces in the range of 1kN. The sum of the forces in the linkages "2" represents the total tractive effort of the bogie.

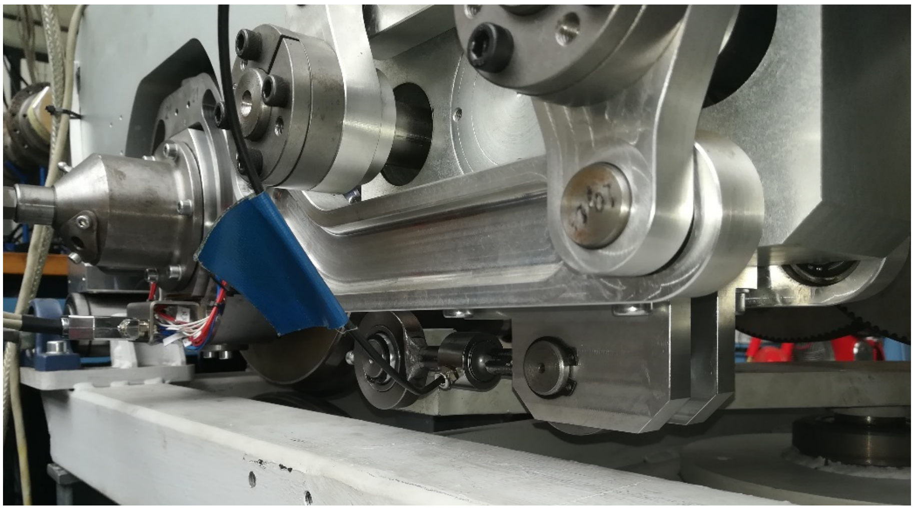

Fig. 7: Detailed photo of instrumented linkage

First tests

The first test of the measuring system was focused on the measurement of longitudinal forces. The system of the measurement of lateral roller disc deformation was not evaluated, as well as the vertical and lateral components of the axle-box forces. The setup of the experiment is depicted on the Fig. 8.

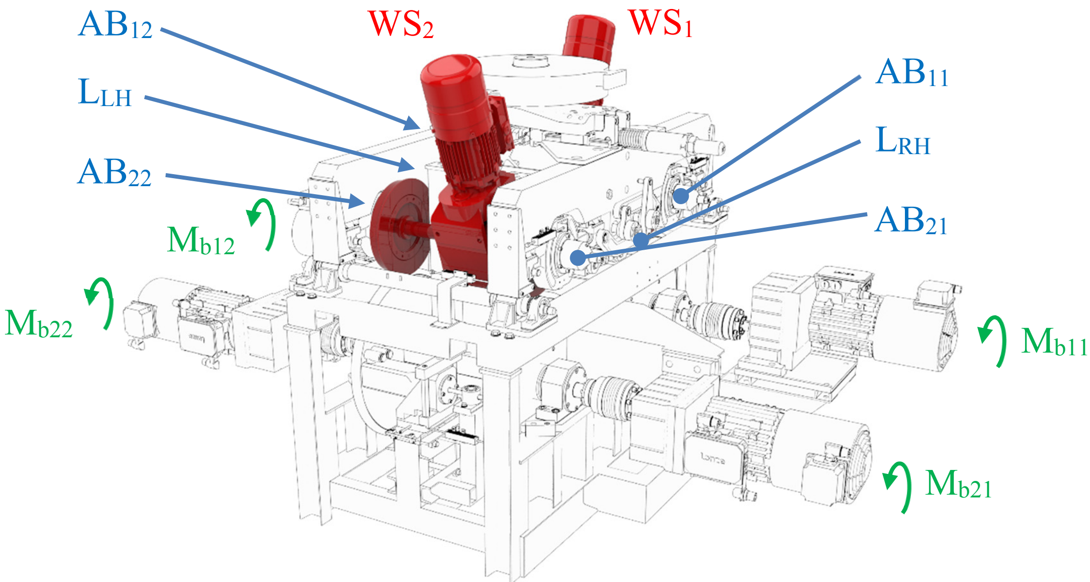

Fig. 8: Experiment setup

Wheelset traction motors WS_1, WS_2 were controlled to the constant speed of 1500 RPM, which corresponds to the vehicle running at a constant speed. The roller drives run in generator mode and simulated the vehicle's resistance forces. At the beginning of the experiment, the braking torques of the roller drives M_{b11}, M_{b12}, M_{b21}, M_{b22} were set to zero. The first index of the designation represents the wheelset number (1 … the first, 2 … the second wheelset of a bogie), the second index determines the side of the vehicle (1 … right side, 2 … left side). At a certain point in time, the braking torques of all four roller were abruptly changed to the constant non-zero value. The response of the axle-box force measurement system and tractive effort measurement system was monitored and compared to the simulation results obtained by a MBS model (Fig. 1, right). Measurements were made for different magnitudes of brake torque M_b. The results for M_b = 50 Nm are shown the Fig. 9 – 11.

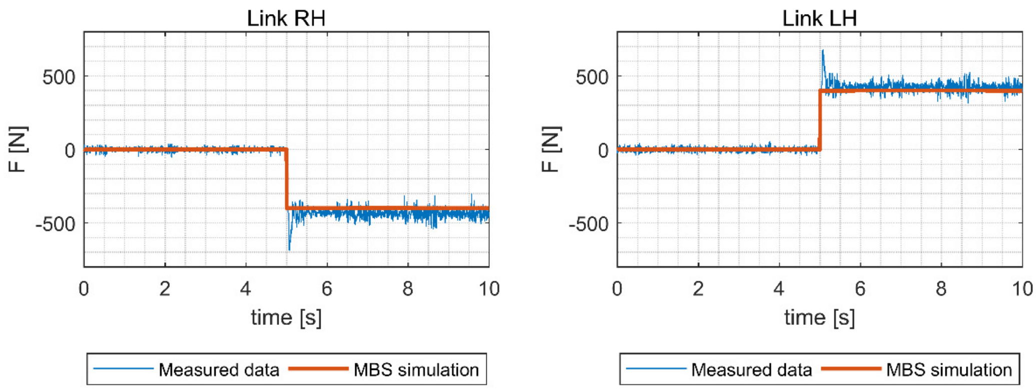

Fig. 9: Forces in linkages

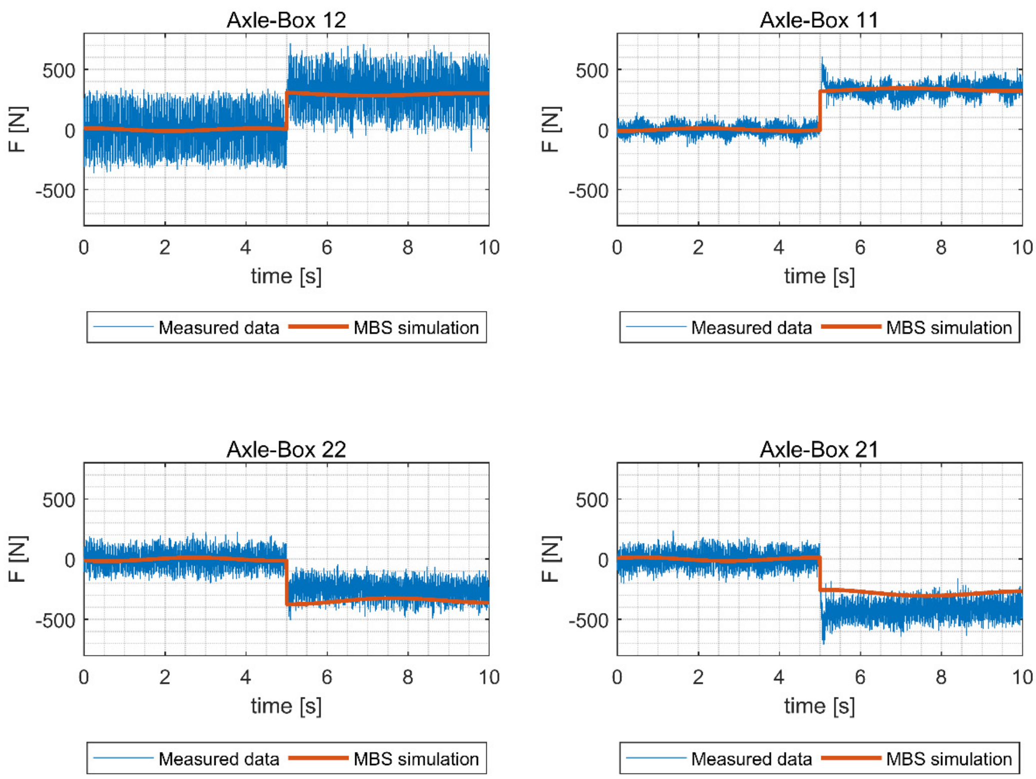

Fig. 10: Longitudinal component of axle-box forces

The measured forces in the linkages (Fig. 9) correspond very well with the simulation results. However, the simulation results give slightly lower values compared to the measured data. This is probably due to the fact that the simulation model do not incorporate the bearing and gear pairs resistances which increase the total brake torque of the roller drives. The mean value of the measured and calculated forces in linkages differs by a maximum of 7%.

The measured axle-box forces (Fig. 10) revealed some defects in the experimental bogie. On the axle-box 11 the force oscillations are apparent. Its' frequency corresponds to the wheelset RPM. This can be caused by a damage on the wheel running surface or by a damage of the axle-box bearing. Moreover, axle-box forces on the wheelset 2 are unevenly distributed. The axle-box 21 transmits grater longitudinal force than the axle-box 22. Based on this, the geometric deviation from the nominal position of the wheelset 2 setup can be deduced.

Nevertheless, the sum of longitudinal axle-box forces acting on individual wheelsets (Fig. 11) shows a very good match with the simulation results. The mean value of the measured and calculated sum of axle-box forces over all tests differs by a maximum of 7%.

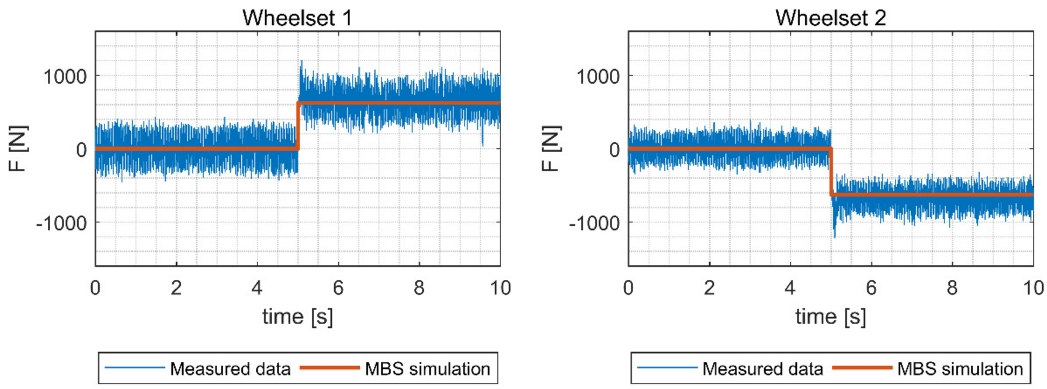

Fig. 11: Sum of longitudinal components of axle-box forces

Conclusions

The magnitude of the forces acting in the wheel-rail contact is an essential criterion for assessing the wear of wheels and rails. Because the wheel-rail contact forces are not measureable directly, the three different systems of force measurement, which could be used for determination of wheel-rail contact forces were implemented at the CTU roller rig. The first tests of these systems were focused on the longitudinal component of axle-box forces and overall bogie tractive effort measurement. The tests confirmed the functionality of the measuring system and showed a relatively good agreement of the simulation and the measured data. At the same time, these tests revealed some possible defects of the experimental bogie and pointed out the necessity to refine the simulation model.

Acknowledgement

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