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System of Axle-Box Force Measurement for Experimental Railway Bogie

BAUER Petr[1,a] and KALIVODA Jan[1,b]

[1] Czech Technical University in Prague, Faculty of Mechanical Engineering, Department of Automotive, Combustion Engine and Railway Engineering, Technická 4, 166 07, Prague 6, Czech Republic

[a]Petr.Bauer@fs.cvut.cz, [b]Jan.Kalivoda@fs.cvut.cz

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Abstract. The article describes the newly developed system for measuring axle-box forces, i.e. forces acting between a bogie-frame and axle-boxes of an experimental railway bogie. One component of the wheelset guidance system was specifically designed was designed with the aim to serve as a three axis load cell. The measurement system was designed to measure x, y and z components of axle-box force independently of each other and independently of the passive resistances in the wheelset guidance mechanism. It consists of 36 strain gauges connected into the three Wheatstone bridges. The load cell design and calibration results are described in detail.

Introduction

Force interaction between rails and railway wheels is undoubtedly one of the most important issues in the development and qualitative evaluation of each railway vehicle. The permitted maximum values of forces applied by the wheel on the rail are defined in the relevant standards. They are based on safety criteria against derailment and the load capacity of the railway infrastructure. Today's effort to build an economic and environment friendly railroad brings a general and sustained demand to reduce wheel-rail contact forces below these legislative limits as much as possible. Reduction of the wheel-rail forces causes not only decrease of vehicle and track wear, it also reduces noise emissions, energy consumption, etc. Therefore, the reduction of wheel-rail contact forces is one of the most important objectives of a long term research activities at the Department of Automotive, Combustion Engine and Railway Engineering CTU in Prague. In order to verify and demonstrate results of mathematical simulations an experimental facility in the form of a roller rig and 1:3.5 scaled experimental bogie [1, 2] is utilized, see Fig. 1.

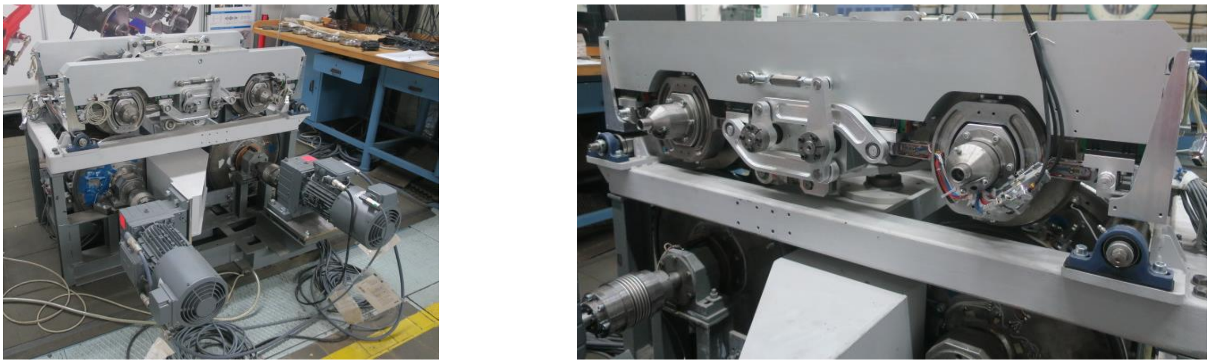

Fig. 1 The experimental railway bogie at the CTU roller rig

Measurement of contact forces directly in the wheel-rail contact point is virtually impossible. In practice, indirect detection of these forces is used. It is based on the measurement of the strain on the appropriate vehicle parts [4, 5] or the measurement of the deformations of the suspension parts. With respect to the inertia effects of the vehicle components, it is desirable to carry out this measurement as close as possible to the wheel-rail contact point. During rail vehicle homologation tests, the measurement of deformations of wheel disks, wheelset axles, or specially instrumented track sections are used.

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

In the case of experimental roller rig bogie, it is possible to use similar approach. However, it is necessary to take into the account also its specificity. At the CTU experimental bogie, the small diameter and high stiffness of the wheel discs as well as frequent need of mounting intervention to the wheelset setup, (3 types of wheelset and several wheel treads with different taper grade are available) would significantly complicate the use of the wheelset for wheel-rail force measurement. Therefore, a system for measuring the lateral component of wheel-rail forces, utilizing transverse roller disk deformation measurement, was developed and applied on all 4 rollers [3]. Although it was not possible to tune the shape of the rollers, hereby formed wheel-roller contact force measurement has a sufficient sensitivity in the lateral direction. By the other hand, the rollers with the current shape and stiffness of the disk are hardly applicable for measurements of the vertical component of wheel-rail force.

Design of a system for axle-box forces measurement

Information on the magnitude of forces between the axle-boxes and the bogie frame are not regarded as an adequate substitute for information about the value of wheel-rail contact forces. The resultant of axle-box forces acting on one wheelset and corresponding resultant wheel-rail forces differ due to the inertia effects of the wheelset. Moreover, from the measured values of axle-box forces it is not possible to determine the distribution of wheel rail forces on the individual wheels. Nevertheless, the axle-box force measurement has significantly meaningful value. The advantage of the measurement of axle-box forces is its relatively easy realization on the vehicle without need to transmit the signal from the rotating parts. Although further development of wheel-rail forces measurement by measurement of roller disc deformation is still planned, it was decided to implement also axle-box forces measurement to the wheelset guidance of the newly developed test bogie. The goal is to measure forces transmitted at each axle-box to the bogie frame in 3 directions:

- F_x – longitudinal component, based on F_x it is possible to calculate action torque of the wheelset steering mechanism,
- F_y - lateral component, F_y provides information on the sum of lateral component of wheel-rail forces.
- F_z - vertical component, F_z provides information on the vertical wheel-rail forces

Load cell design. Considering several possible solutions, the development of a newly designed 3 axis load cell was finally chosen. The main advantage of this solution compared to implementation of industrially produced 3-axis load-cells, is the possibility to adapt certain components of wheelset guidance for axle-box force measurement. This significantly simplifies the design of wheelset guidance itself. In the final design solution (Fig. 2), the axle-box (item 9) is guided by stirrup (item 8), which is on both ends connected by spherical joints (items 6a, b) to the carriages of linear guideway (items 7a, b). Connection of the axle-box and the stirrup is provided via a cylindrical joint (bearings 11a, b). The axle-box can thus rotate around vertical axis towards the stirrup. The end shanks of the stirrup are aimed for the strain gauges placement. The longitudinal axis of the end shanks is at the height of the wheelset axis and also the axis of the control linkages joints is at the same height. Thus, in terms of measurement the stirrup is a beam supported by two supports and loaded by individual components of the axle-box force.

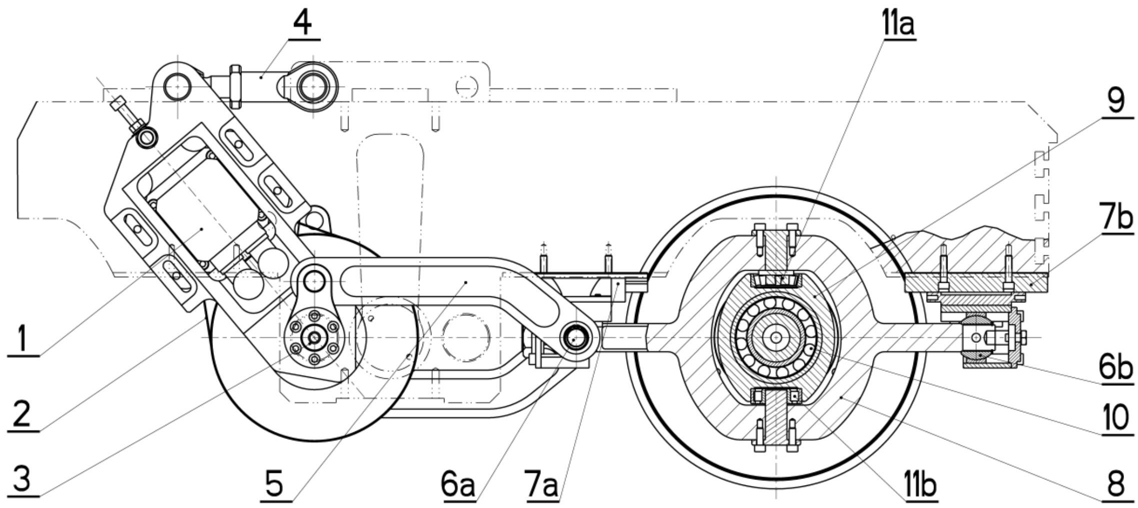

Fig 2 Design of the wheelset steering mechanism and the connection between axle-box and bogie frame

The overall concept of the test bogie expects vertical loading in order to simulate the weight of the vehicle body. For dimensioning of the stirrup in terms of loads F_y and F_z, the maximal vertical load acting upon the test bogie is taken into the account. The magnitude of maximal longitudinal load F_x is given by the maximal yaw torque applied upon a wheelset by the wheelset steering mechanism. Based on these assumptions, the maximal loads of single axle-box load cell are:

- Fx … 2.5 kN
- Fy … 5 kN
- Fz … 5 kN

The stirrup is made of heat-treated C45 steel. Its design was subjected to FEM calculation and shape optimization (Fig 3), in order to achieve as high as possible sensitivity on one hand and not to exceed 500 MPa von Mises stress on the other.

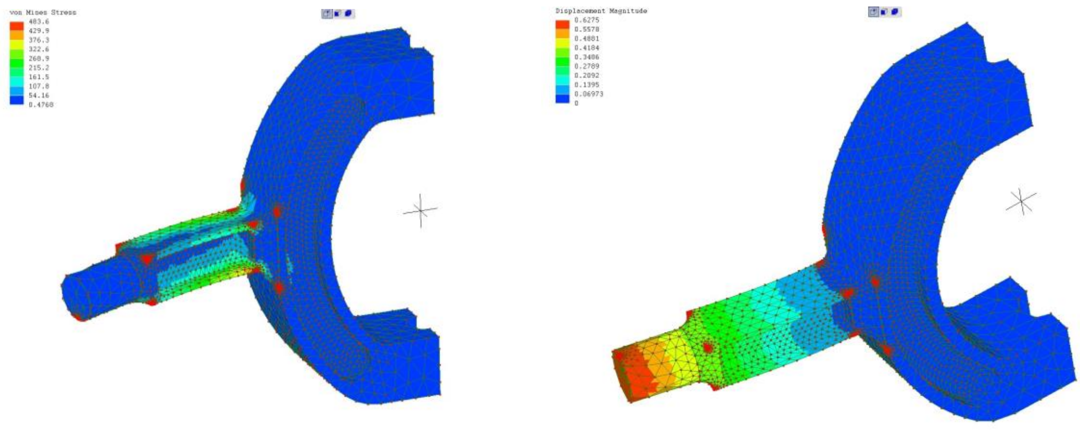

Fig. 3 Sample results of the stirrup FEM analysis. Von Mises stress upon maximum load in all three axes all at once (left). Displacement upon lateral load only (right).

F_x – measurement of the longitudinal component of the axle-box force. The longitudinal position of the axle-box is driven by means of control linkages connected to one of the carriages of a ball linear guide. The force transmitted by linkages F_{CL} (see Fig 4) is the sum of the longitudinal axle-box force F_x and the resistance forces of the linear guides F_{R1} and F_{R2}. In the whole x-section of the shank, closer to control linkages, the normal stress, which is measured by strain gauges T_{x1i} and T_{x1e}, is proportional to sum of the axle-box force F_x and the resistant force of the more distant carriage F_{R2}. Whereas the normal stress at second shank, which is measured by strain gauges T_{x2i} and T_{x2e}, is proportional to resistant force of the more distant linear carriage F_{R2} only. Strain gauges for the measurement of F_x are placed on both sides of the shanks on their neutral axis. Connection of the strain gauges in Wheatstone bridge will automatically compensate resistant force of linear guides from the measured signal (Fig. 4). Also the influence of bending moment originating from lateral axle-box force F_y will be automatically compensated. Due to the placement of strain gauges to the neutral axis, the output signal should be also insensitive to the load caused by the vertical axle-box force F_z.

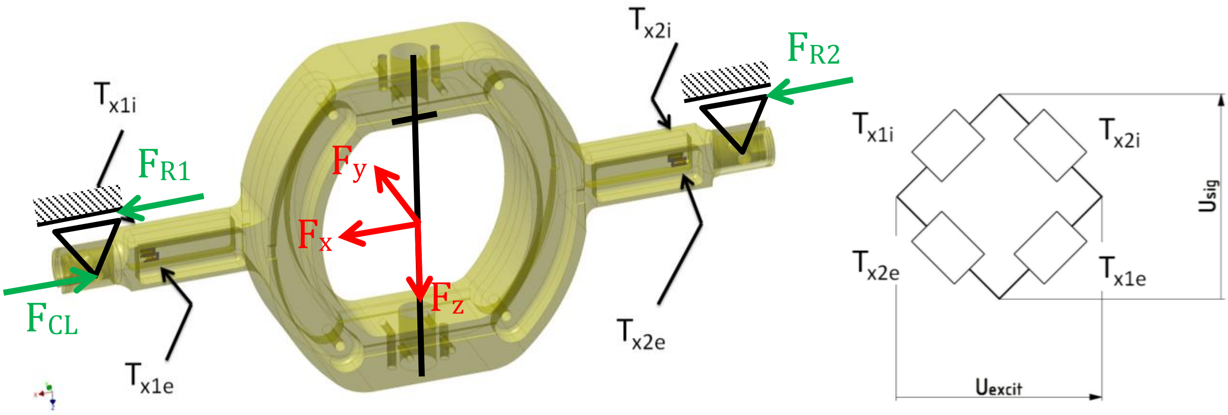

Fig. 4 System for the measurement of the longitudinal component F_x of the axle-box force. Strain gauges position (left) and wiring diagram (right).
$T_{x..}$ – strain gauge designation, F_{CL} – force transmitted by the control linkages, $F_{R.}$ – resistant forces of the linear guides, U_{excit} - power supply of the Wheatstone bridge, U_{sig} – measured response.

F_y – measurement of the lateral component of the axle-box force. Lateral axle-box force F_y bends both the shanks in the horizontal plane and causes strain difference on the inner and outer sides of the shank. Assuming that the stirrup is supported by ideal spherical joints, four strain gauges would be sufficient for measurement of F_y. However, the joints resistance is not negligible. Due to the internal friction, both of the end joints will act by a certain moment, which could influence the measured value of lateral force F_y. Therefore, the proposed system is based on 16 strain gauges (Fig. 5). Compensation of the joints resistance is based on the assumption that the joint friction torques cause a constant bending moment along the shanks. By placing the strain gauges into the two sections and subtracting the signals from those two sections a signal proportional to the lateral force F_y load without influence of friction moments is obtained.

F_z – measurement of the vertical component of the axle-box force. The vertical axle-box force F_z again bends both shanks, but this time in the vertical plane. Measurement of force F_z is by principal analogical to the measurement of the lateral force F_y (Fig. 6).

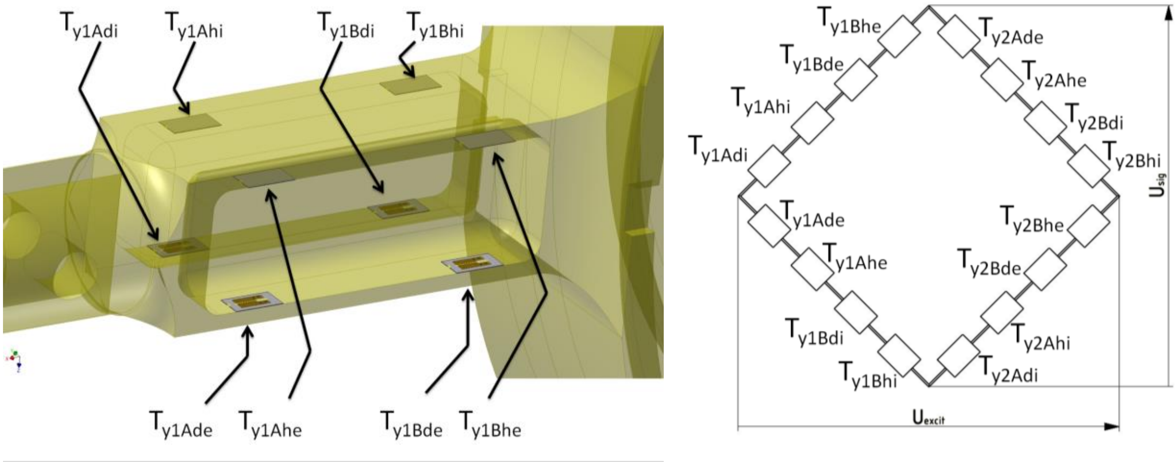

Fig. 5 System for the measurement of the lateral component F_y of the axle-box force.
Strain gauges positions on shank 1 (left), wiring diagram (right).
Strain gauges positions on shank 2 are analogous.

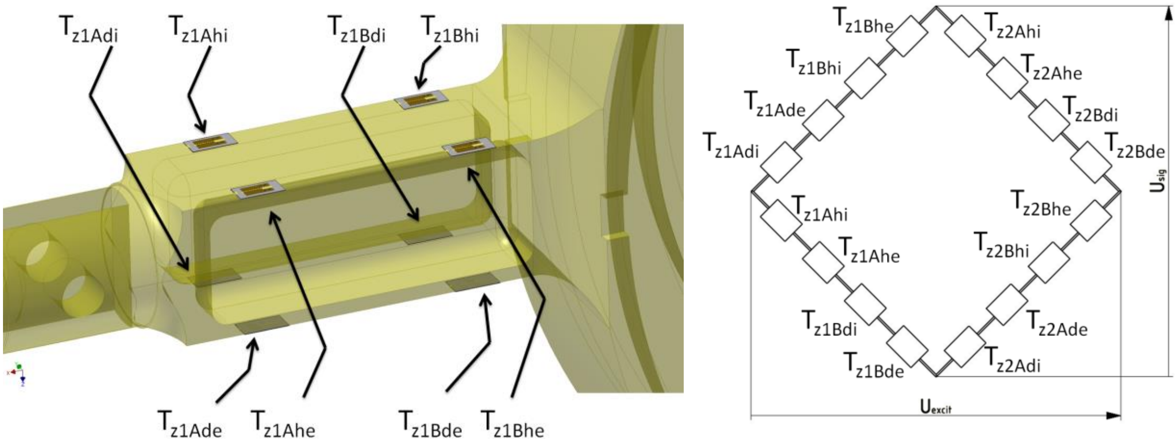

Fig. 6 System for the measurement of the vertical component F_z of the axle-box force.
Strain gauges positions on shank 1 (left), wiring diagram (right).
Strain gauges positions on shank 2 are analogous.

Calibration

The proposed system was implemented on the experimental railway bogie. The stirrup was instrumented by strain gauges and calibrated (Fig. 7). During the calibration, the stirrup was gradually loaded in the x, y and z axes in the range of 0 to 3 kN (see charts on the left on Fig 8, 9, 10). The response of the strain gauge bridges was monitored and compared to the response of calibration load cell. The charts on the right on Fig 8, 9, 10 shows the difference between directly measured stirrup load and the response of stirrup. The difference did not exceed 30 N, which is less than 1% of the measured range. At the same time, the ability of the system to measure independently the x, y and z components of the axle-box forces was confirmed. The mutual influence of the load components is less than 15 N, see the response in unloaded directions on Fig 8, 9, 10.

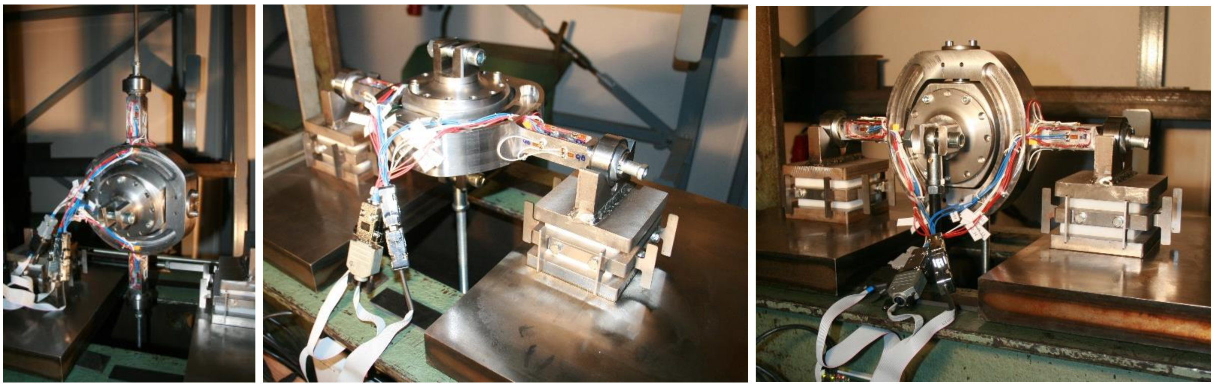

Fig. 7 Stirrup calibration in x (left), y (middle) and z (right) direction

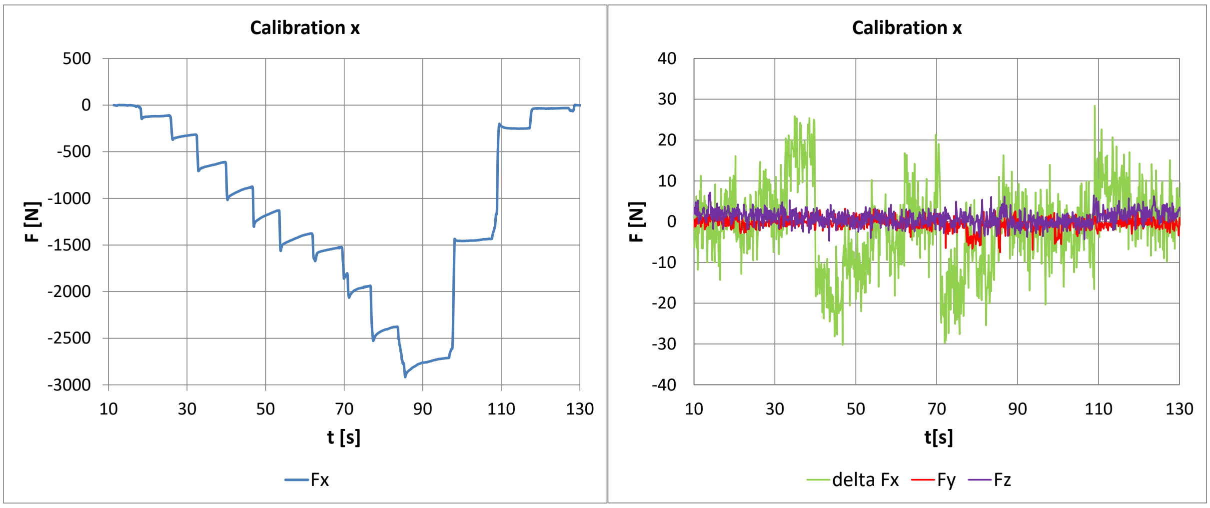

Fig. 8 Calibration data. Stirrup calibration in x direction

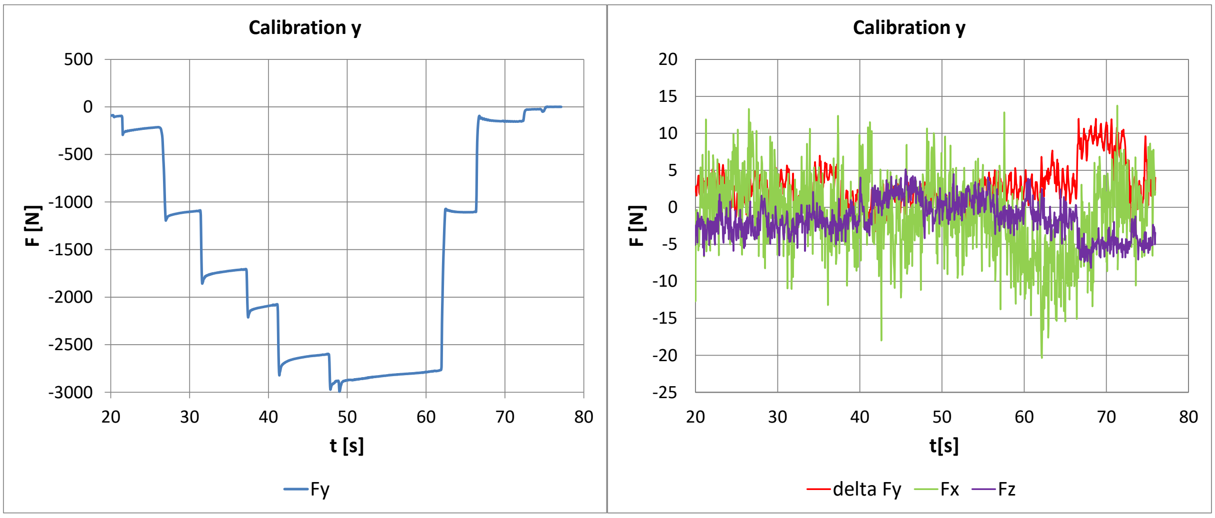

Fig. 9 Calibration data. Stirrup calibration in y direction

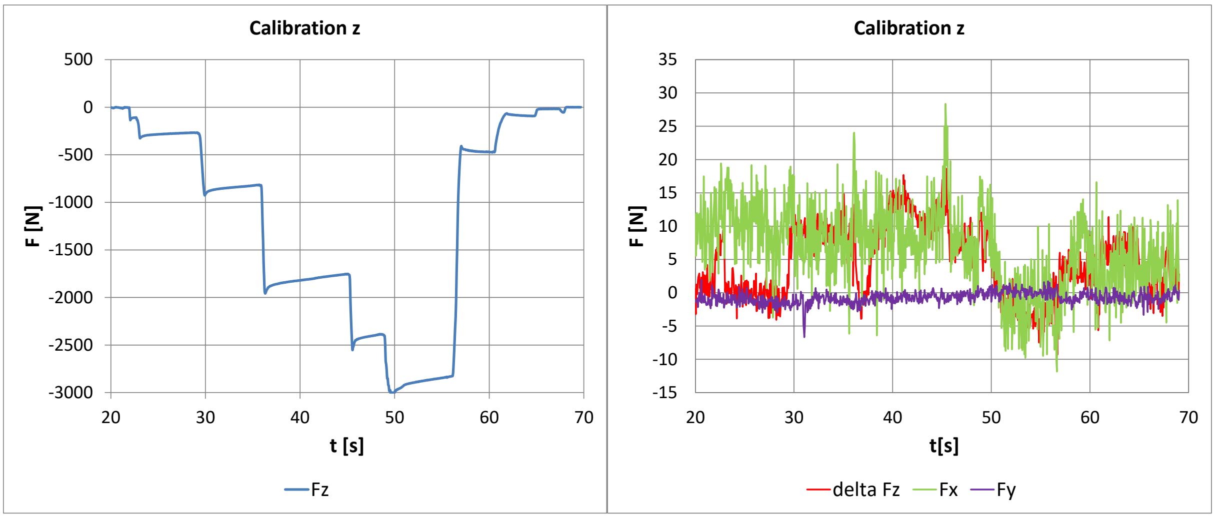

Fig. 10 Calibration data. Stirrup calibration in z direction

Conclusions

The magnitude of wheel-rail contact forces is one of the most important parameters that influences wear of wheels and rails, safety against derailment and many other important parameters of the operation of railway vehicles. Therefore, the reduction of force acting in the wheel-rail contact is still an essential topic in the development of new rolling stock. Because the direct measurement of forces acting in the wheel-rail contact is not possible, it is necessary to determine these forces indirectly, usually by measurement of the deformation of the wheels, rails or other parts of the rail vehicle bogie. One of the parameters, which can be used to determine the magnitude of the wheel-rail contact forces are axle-box forces, i.e. the forces acting between the axle-boxes and the bogie frame. A system capable to measure axle-box forces on the experimental railway bogie was designed. The system is based on stirrup specifically designed component that connects the axle-box and the bogie-frame. The bogie is equipped by four stirrups, one per each axle-box. Each stirrup is instrumented by 36 strain gauges connected to three full bridges. Thus measurement of x, y and z components of a force transmitted between each axle-box and the bogie frame is achieved. The system was successfully calibrated and implemented to the experimental railway bogie. The experimental bogie is thus prepared to conduct experiments focused on reducing the mutual interaction of railway vehicles and the track.

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References

[1] S. Myamlin, J. Kalivoda and L. Neduzha, Testing of Railway Vehicles Using Roller Rigs [online]. Procedia Engineering. 2017, 2017(187), pp. 688-695. ISSN 1877-7058. doi: 10.1016/j.proeng.2017.04.439.

[2] J. Kalivoda and P. Bauer, Mechatronic Bogie for Roller Rig Tests. In: Six, K., et al., eds. IAVSD 2015 - 24th International Symposium on Dynamics of Vehicles on Roads and Tracks. Graz, 17.08.2015 - 21.08.2015. Boca Raton: CRC Press. 2015, ISBN 9781138028852.

[3] J. Kalivoda and P. Bauer, Scaled Roller Rig Experiments with a Mechatronic Bogie, in: Proceedings of the Second International Conference on Railway Technology: Research, Development and Maintenance. Edinburgh: Civil-Comp Press, 2014, art. no. 317, ISSN 1759-3433. ISBN 978-1-905088-59-1.

[4] M. Dub, J. Kolář, F. Lopot, V. Dynybyl and O. Berka, Experimental analysis of stress state and motion of tram gearbox hinge, in: EAN 2014 - 52nd International Conference on Experimental Stress Analysis, 2014.

[5] S. Myamlin, O. Ten, L. Neduzha, Theoretical and experimental research of strength properties of spine beam of freight cars. in: Science and transport progress. № 3 (51), 2014, pp. 136–145.