Jaromír Zelenka, Tomáš Michálek, Martin Kohout

Wheel/rail contact geometry research and development of locomotive Class 744.0 as examples of R&D activities of the Jan Perner Transport Faculty

The Jan Perner Transport Faculty (JPTF) of the University of Pardubice and especially its Department of Transport Means and Diagnostics deals with research and development activities in the branch of railway vehicles. There are two basic reasons for that. At first, it is incumbent upon all academic workers to pursue the science and research according to the Czech law concerning the universities. And the second reason is a relation to the educational process – if the JPTF wants to offer a high quality education in the specialization "Railway Vehicles" (which is offered in Czech as well as English language today) to its students, the research activities of the academic workers (i.e. the teachers) allow them to stick to the newest trends in the branch. In this article, particular examples of cooperation of the JPTF with producers as well as operators of railway rolling stock are presented as a contribution of the faculty to the research and development in the branch of railway vehicles.

R&D activities of the Jan Perner Transport Faculty

The main specialization of the research activities of the railway vehicle department is oriented on dynamics of railway vehicles and vehicle/track interaction. These activities cover theoretical research of running performance of railway rolling stock using computer simulations, experimental research (measurements on vehicles as well as on test stands), assessment of the wheelset/track interface (characteristics of wheel/rail contact geometry, adhesion, effects of running vehicles on the railway superstructure), traction dynamics etc. For purposes of support of the experimental research as well as the education of technically oriented study specializations at the JPTF, the new Educational and Research Centre in Transport (ERCT; see [2]) was opened in Pardubice in 2013. Between the testing devices, which are installed in the ERCT, following equipment can be found today:

- dynamic test stand (fig. 1), which is used e.g. for testing of stiffness characteristics of suspension elements of vehicles, characteristics of dampers, strength and service life of steel and concrete structures etc.;
- wheel/rail test stand (fig. 2), which is used e.g. for development of systems for measurement of forces acting in wheel/rail contact – i.e. instrumented wheelsets (see also paper [1]), this testing equipment allows laboratory simulation of operation conditions in wheel/rail contact up to 20 tons of axle load and speed up to 200 km/h in full scale;
- tram wheel test stand with permanent magnet synchronous motor (PMSM) traction drive (fig. 3), which is used for research of adhesion characteristics (see e.g. paper [7]) and also the workers of the Department of Electrical and Electronic Engineering and Signalling in Transport use it for purpose of research activities in the branch of traction drive regulation.

On the theoretical level, the dynamics of railway vehicles is investigated especially by means of computer simulations. For these purposes, an original multi-body simulation tool "SJKV" (in Czech: *Simulace jízdy kolejového vozidla*; in English: *Simulation of Rail Vehicle Run*) is being developed at the JPTF since 1990's. This simulation software is based on the principle of dynamics of rigid bodies which are coupled with elastic and damping – in general case non-linear – joints. The system is being developed in the IDE Borland Delphi and it is created with specialized program units (for solving of individual tasks of the simulation), which allow creating of different modifications of the system for various railway vehicles. A more detailed description of the simulation tool "SJKV" (together with an example of particular application – modelling of active elements) can be found e.g. in paper [5]. Besides to the system "SJKV", the commercial simulation tool SIMPACK is also used at the JPTF for investigation of vehicle dynamics.

Fig. 1. *Dynamic test stand in the ERCT; photo: ERCT [2]*

Fig. 2. *Wheel/rail test stand in the ERCT; photo: ERCT [2]*

Fig. 3. *Tram wheel stand with PMSM drive; photo: ERCT [2]*

Example No. 1: Wheel/rail contact geometry

A special part of the R&D activities is focused on the wheel/rail contact geometry. The wheelset/track contact conditions influence running performance of vehicles in the straight track as well as in curves very significantly. Especially in small-radius curves, the contact geometry is related with wear of wheels and rails. Therefore, several wheel profiles for specific conditions were proposed on the JPTF, e.g. wheel profiles for trams in Prague and Brno or a wheel profile for metro cars in Prague. This metro wheel profile, called as "KUŽEL-2A", was introduced in operation in 2000. Subsequently, wear of the new wheel profile was observed and compared to the wear of the original wheel profile UIC-ORE. For the evaluation, both types of metro trains operated in Prague were used – modernized Russian train type 81-71M as well as new Siemens train type M1. In fig. 4, there are presented averaged values of a mass decrease of a wheel profile (i.e. of one wheel) in kg per 10 000 km for 5 observed train units. It is evident that these values (i.e. approximately 30 up to 110 g per 10 000 km in case of both wheel profiles) are very low in comparison with standard conditions on the railway. A very slow progress of the wear can be also illustrated by the fact that the wear of wheel tread as well as the wear of flange is usually lower than 0.5 mm at a kilometric run of 100 000 km. Besides the wear, the conditions of wheel/rail contact geometry were observed, as well. A significant difference between both wheel profiles is the fact, that the UIC-ORE wheel profile shows in the operation a gradual flattening. It is demonstrated in fig. 5 – white bars present the equivalent conicity (for the amplitude of wheelset lateral motion of 3 mm) of a theoretical wheel profile on the rails S49/1:20, colored bars present the real equivalent conicity immediately after the turning of wheelsets and cross-hatched bars present the real equivalent conicity after the given kilometric run. In case of the metro unit "3", a zero value was even reached – it means that the wheelsets shows similar properties as a wheelset with cylindrical wheel profile (including the degradation of the guiding ability of the wheelset on the track). In case of the KUŽEL-2A wheel profile, this effect is not observed; the shape change of the wheel profile leads to an increase of the equivalent conicity up to a value of ca. 0.3. Nowadays, the co-operation of the JPTF with the metro operator is continuing and the operation of the new wheel profile is evaluated on the basis of long-time observation of the trains.

In field of railway applications, the specially developed wheel profiles ZI-3 and ZI-4, which take into account the coexistence of rail inclinations 1:20 and 1:40 on the Czech railway network, are used on some types of vehicles of the Czech Railways (ČD). Besides to that, a proposal of asymmetrical rail profiles for application in small-radius curves was performed to improve the contact geometry and force conditions between the vehicle and the track (see e.g. paper [3]). Nowadays, a test track section with asymmetrical wheel profiles is observed in the regular operation on the Czech railway network.

Data characterizing the wheel/rail contact geometry also serve as input parameters for the multi-body simulations of ve-

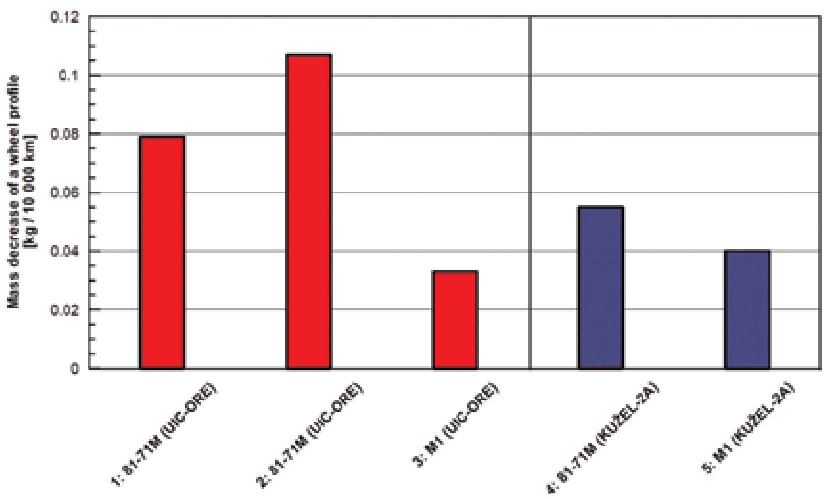

Fig. 4. *Averaged values of mass decrease of a wheel profile (red: UIC-ORE, blue: KUŽEL-2A) for 5 metro units*

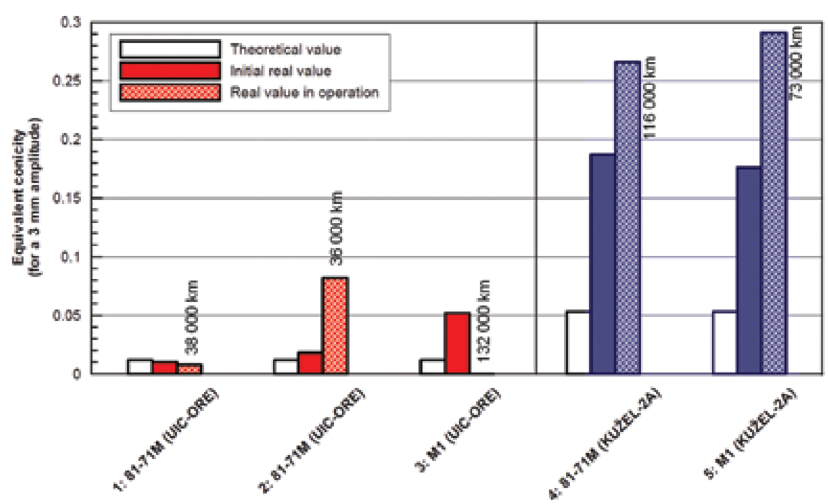

Fig. 5. *Progress of the equivalent conicity of averaged wheel profiles of the 5 observed metro units*

Fig. 6. *Testing of a secondary flexi-coil spring on the dynamic test stand*

Fig. 7. *Prototype of the standard-gauge locomotive 744.001 on the fair Czech Raildays 2012 in Ostrava (CZ)*

hicle running performance. And measurement of wheel and rail profiles can be realized by the Testing laboratory of the JPTF, which is accredited according to the EN 17025:2005, as an accredited test for purposes of determination of the wheelset/track contact geometry.

Example No. 2: Locomotive Class 744.0

In the next, the research activities will be presented on a specific example of applied research. In years 2010 to 2012, the JPTF co-operated with the company CZ LOKO on the research and development of a four-axle diesel-electric locomotive Class 744.0. This R&D project was supported by a grant of the Ministry of Industry and Trade of the Czech Republic and its target was manufacturing of a standard-gauge prototype of the locomotive as well as a preparation of a “virtual prototype” of a broad-gauge version of the locomotive (intended for the track gauge 1520 mm) according to the GOST standards.

In the first stage, a new version of the multi-body simulation tool SJKV-Lok744 was created. This version of the simulation software took into account the basic concept of the locomotive, i.e. wheelset guiding realized by connection rods, primary as well as secondary suspension consisting of flexi-coil springs and damped by hydraulic dampers, transmission of longitudinal forces between the vehicle body and bogie frame by means of a central pivot, nose-suspended axle-mounted asynchronous traction motors etc. With using of this software, preliminary simulations of running and guiding behaviour of the locomotive were performed. The aim of these simulations was an investigation of the influence of input parameters of the vehicle model (total mass, characteristics of joints, characteristics of wheel/rail contact geometry etc.) on its dynamic performance, especially on guiding forces in small radius curves and on the running stability in straight track at higher speeds. Besides to that, e.g. an influence of the nose-suspended traction drive (of the unsprung masses in running gear of the vehicle, generally) on vehicle/track interaction was quantified by means of simulations (see paper [4]).

During the further development of the locomotive, the input parameters of the computational model were specified on basis of cooperation with designers as well as on basis of laboratory measurements. These measurements, which were realized on the dynamic test stand of the JPTF in Pardubice, were used especially for purposes of verification of stiffness parameters of real suspension elements (axial and lateral stiffness of primary and secondary springs, stiffness of connection rods of wheelset guiding). In fig. 6, there is depicted a secondary flexi-coil spring at testing of its lateral stiffness as an example. Beside to that, the bogie frame was subjected to the FEM calculations to verify its mechanical strength.

The prototype of the standard-gauge locomotive 744.001 (fig. 7) was completed by the company CZ LOKO in 2012. In this year, the track tests of running performance of the locomotive were also realized. These measurements were performed on selected lines of the Czech railway network in cooperation with the company VÚKV [6]. Whilst the researchers from the JPTF secured accredited measurements of acceleration on individual parts of the locomotive (i.e. the simplified measuring method according to the UIC Code No. 518), their colleagues from VÚKV performed additional measurements of wheel/rail forces with using of an instrumented wheelset. At these tests, the maximum speed of the locomotive of 120 km/h increased

Tab. 1. Comparison of results characterizing dynamic behaviour of the locomotive obtained in various ways

	Analytical calculation	Simulation SJKV-Lok744	Simulation SIMPACK	Measurement on real vehicle
Eigenfrequency of pitching of the vehicle body	approx. 1.45 Hz	1.39 Hz	1.30 Hz	approx. 1.4 Hz
Wheel load change on limit track twist (acc. to EN 14363)	24.0 kN	23.9 kN	–	approx. 27 kN
Vehicle body roll coefficient	–	0.17	0.16	0.16 up to 0.18

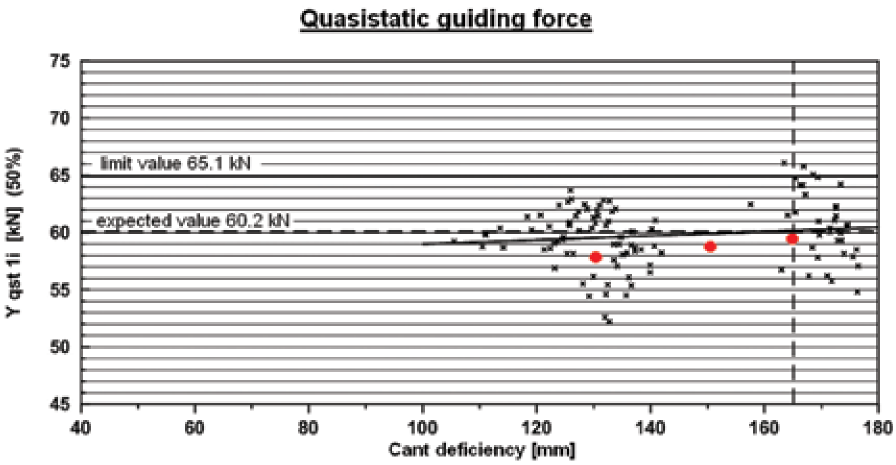

Fig. 8. *Comparison of results of measurement and simulation (red dots) – quasistatic guiding force on leading wheel in small-radius curves*

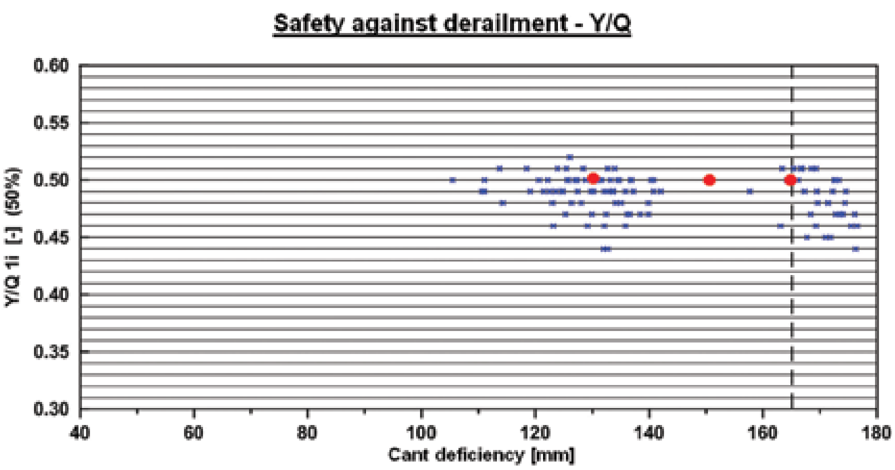

Fig. 9. *Comparison of results of measurement and simulation (red dots) – Y/Q ratio on leading wheel, characterizing the safety against derailment in small-radius curves*

about 10% was reached. Subsequently, the obtained results were used for acceptance process of the locomotive in the Czech Republic as well as for validation of the computational multi-body model.

As it was mentioned above, the model validation was performed in the final stage of development of the locomotive. For this model validation, four various sources of results were used – the simulation results from the multi-body system "SJKV-Lok744", the results from measurement on the real vehicle (track tests as well as quasistatic tests on the testing devices in VÚKV) and additionally also simulation results from a computational model created in the simulation tool SIMPACK and analytical calculations (eigenfrequencies, wheel load change on twisted track). As it is demonstrated on selected data in table 1, all used methods show relatively good agreement. A comparison of simulated and measured values of quasistatic guiding forces and Y/Q ratio in small-radius curves is shown in fig. 8 and 9. All the results show a good credibility of the results obtained by means of the simulation tool "SJKV" and confirm a suitability of utilization of multi-body computer simulations in design stage of new (or modernized) railway vehicles as an effective tool for optimization of their parameters.

References:

1. Čapek, J.; Malinský, J.; Moureček, Z.; Culek, B.: *Measuring wheelset system VÚKV 3 and its using possibilities*. 20th International Conference Current Problems in Rail Vehicles – PRORAIL 2011, Proceedings, Vol. 1.
2. *Educational and Research Centre in Transport*. Web presentation of the University of Pardubice. http://www.upce.cz/english/jptf/erct.html
3. Kohout, M.; Zelenka, J.; Hába, A.: *Studies of wheel-rail contact conditions in curves of small radius*. 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems – CM 2009, Proceedings, Vol. 2.
4. Michálek, T.; Zelenka, J.: *Dynamic behaviour of locomotive with axle-mounted traction motors*. International Conference Engineering Mechanics 2012, Conference Proceedings.
5. Michálek, T.; Zelenka, J.: *Reduction of lateral forces between the railway vehicle and the track in small-radius curves by means of active elements*. "Applied and Computational Mechanics" 2011, Vol. 5, No. 2.
6. *Research, development and testing of railway rolling stock*. Web presentation of the VÚKV a.s., http://www.vukv.cz/home-en
7. Voltr, P.; Lata, M.: *Transient wheel-rail adhesion characteristics under the cleaning effect of sliding*. "Vehicle System Dynamics" 2015, Vol. 53, No. 5.

Authors:

doc. Ing. **Jaromír Zelenka**, CSc. – University of Pardubice, Jan Perner Transport Faculty, Department of Transport Means and Diagnostics, Section of Rail Vehicles, Czech Republic

Ing. **Tomáš Michálek**, Ph.D. – University of Pardubice, Jan Perner Transport Faculty, Department of Transport Means and Diagnostics, Section of Rail Vehicles, Czech Republic

Ing. **Martin Kohout**, Ph.D. – University of Pardubice, Jan Perner Transport Faculty, Department of Transport Means and Diagnostics, Section of Rail Vehicles, Czech Republic

Badania geometrii kontaktu koło / szyna i badania lokomotywy serii 744.0 jako przykłady działalności R&D Wydziału Transportu Jana Perner

W artykule przedstawiono aktywność badawczą Wydziału Transportu Uniwersytetu w Pardubicach (Czechy) w zakresie pojazdów kolejowych. Scharakteryzowano wyposażenie laboratoriów wykorzystywane do badań teoretycznych i eksperymentalnych. Skoncentrowano się na zagadnieniach dostosowania profili kół do specyficznych warunków ruchowych oraz współpracy przy konstrukcji nowej lokomotywy.