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J. KALIVODA[1*], P. BAUER[2*]

[1*]Dep. «Automobiles, Combustion Engines and Railway Vehicles», Czech Technical University, Faculty of Mechanical Engineering, Technická St., 4, Praha 6, Czech Republic, 16607, tel. +(420) 224 352 493, e-mail jan.kalivoda@fs.cvut.cz, ORCID 0000-0002-0278-2515
[2*]Dep. «Automobiles, Combustion Engines and Railway Vehicles», Czech Technical University, Faculty of Mechanical Engineering, Technická St., 4, Praha 6, Czech Republic, 16607, tel. +(420) 224 352 493, e-mail petr.bauer@fs.cvut.cz, ORCID 0000-0002-0940-3303

ROLLER RIG TESTING AT THE CZECH TECHNICAL UNIVERSITY

Purpose. Although the advancements in computer simulation technology have paved way to provide very reliable simulation results, track tests still play an essential role during the process of development and homologation of any railway vehicle. On the other hand, track tests depend on weather conditions, are difficult to organize and are not suitable for testing vehicles in critical situations. On a roller rig, the tested vehicle is longitudinally fixed and a track is replaced by rotating rollers. Such device offer testing of railway vehicle running dynamics in safe and stable laboratory environment. The purpose of an article is to investigate and describe roller rig testing at the Czech technical university in Prague (CTU). **Methodology.** In the paper it is shown the history of development of the scaled CTU roller rig from the earlier stages until the current projects for which the CTU roller rig is utilized for. The current design of the experimental bogie, roller rig, sensors instrumentation and types of experiments conducted at the CTU roller rig are described in more detail. **Findings.** Although the differences in vehicle behaviour on a track and a scaled model on a roller rig are not negligible, scaled roller rig experiments are found as a relatively inexpensive way for verification and demonstration of computer simulations results. They are especially useful for verification of multibody system simulations (MBS) of entirely new running gear concepts. **Originality.** The CTU roller rig is currently used for the experiments with active controlled wheelset guidance. According to simulations results published in many papers such systems offer, in principle, better performance compared to conventional passive vehicles. However, utilization and testing of active controlled wheelset guidance on vehicles is still rare. CTU roller rig serves as a tool to verify computer simulations and demonstrate benefits of active wheelset guidance. **Practical value.** Experiments conducted on the CTU roller rig confirm the possibility to significantly influence railway vehicle running dynamics by actively controlled wheelset guidance. Such concept could be regarded as a possible and likely approach for the design of future railway vehicles running gears.

*Keywords***:** roller rig; active control; wheelset guidance; mechatronic bogie

Introduction

MBS simulations play an important role in the development of rail vehicles with 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 new rolling stock approval. Nevertheless track tests are also very expensive, time consuming and difficult to organize. Therefore, it is almost impossible to perform them under 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 hardly possible to fulfill all safety requirements.

Roller rig testing of railway vehicles is based on replacement of a track by rotating rollers with a rail profile on their circumference. Although on the roller rig a tested vehicle is longitudinally fixed and has no forward velocity, the creep conditions in the wheel-roller contacts are very similar to the creep conditions in wheel-rail contacts on a real track.

The key advantages of railway vehicles laboratory roller rig testing are stable climatic conditions, knowledge of the current state of the track and elimination of safety risks and legislative problems associated with the operation of prototypes in a public railway network. Moreover, in contrast with track tests, roller rigs offer also the advantages of low cost, low spatial demands, a safe and controlled laboratory environment, and ease of access to components and the testing apparatus.

The first know utilization of a roller rig for the investigation of the performance of steam locomotives was in United Kingdom in 1904 [1]. How-

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ever, the most important era of roller rigs utilization came together with the development of high-speed vehicles. From the late fifties until the early eighties last century, roller rigs in Japan, UK, Canada, USA, Italy, France, Germany and Russia, later in China, were built [2]. Once the early stages of high speed vehicle development were successfully finished, the demand for roller rig vehicle testing significantly dropped. Because full-scale roller rigs are rather costly facilities, most of them are out of the operation now and advanced MBS simulations often replace their role in the vehicle development process.

Roller rigs designed for testing scaled models of railway vehicles are called scaled or model roller rigs. The main advantages of scaled roller rig compared to the full scale ones are:

− Manufacturing of the scale rig and test vehicle causes rather decreased expenses.

− Handling and maintenance are comparatively easier.

− A lot of vehicle parameters can be changed with tolerable effort.

However, there are also inconveniences and disadvantages connected with scaling and applying similarity laws [3, 4]. The design of a scaled model always depends on scaling strategy [5] and the area of investigated phenomena. It is not possible to build a scaled model exactly representing all properties of a full scale vehicle.

Purpose

Due to the above mentioned scaling issues, model roller rigs are rarely used for the verification of behaviour of real vehicles. The use of a scaled roller rig is usually focused on:

− Verification and validation of simulation models [6].

− Investigation of fundamental railway vehicles running behaviour [9].

− Development and testing of novel bogie designs [7, 8, 10].

Although MBS simulations give reliable results, it is always necessary to identify model parameters by a comparison with the experimental data. Scaled roller rig experiments are an advantageous way for model parameters identification and consequent demonstration of simulations results.

Typically, scaled roller rigs are not used for assessing the performance of a particular vehicle, but they play an important role in a development of entirely new concepts of running gears and suspensions and in verification of MBS simulations.

Methodology

The history of roller rig testing at the CTU began towards the end of eighties last century, when the first single axis roller rig was built (Fig. 1).

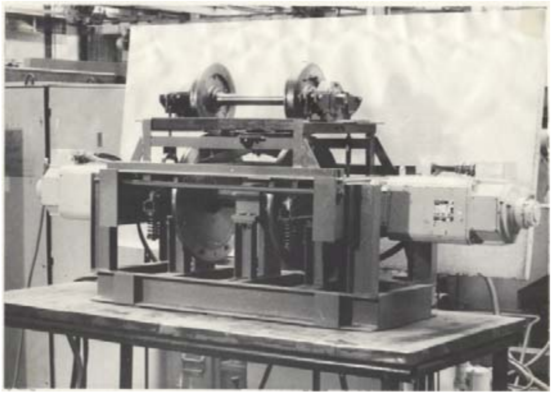

Fig. 1. The first scaled roller rig at the CTU

The scale of the first CTU roller rig was 1 to 3.5 and it remained unchanged until now. The rig was built as an initial step of full scale roller rig development. Because the project of the full scale roller rig has never been started, the first scaled roller rig became a basis for all future roller rig testing at the CTU. The rig has been improved and updated many times, where the design changes were specifically performed mainly according to the objectives of the projects in which the rig was used. The first major modification came during the first half of the 90's, when the rig was completely rebuilt to a 2-axle type configuration (Fig 2). The experimental two-axle bogie had a wheelbase of 714 mm, track gauge of 410 mm and wheels diameter 263 mm. This corresponds to a wheelbase of 2500 mm and 920 mm wheel diameter for real standard gauged vehicle [11, 12]. In the following period the rig was not intensively used.

The new era of the CTU roller rig development took place from 2005 together with the beginning of experiments focused on the behaviour of the wheelsets with independently rotating wheels (IRW) and later with the experiments with active wheelset guidance.

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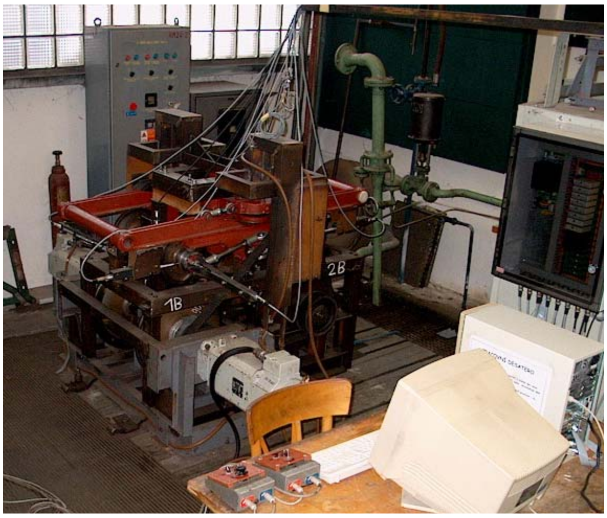

Fig. 2. CTU roller rig after redesign
to 2 axle bogie stand

The main design changes were:

− Replacement of DC roller drives by 3-phase asynchronous motors.

− Possibility to simulate a curved track.

− A system for measurement of wheel roller contact forces.

− Actuated wheelset steering mechanism.

− Data acquisition system based on Matlab-Simulink software.

The state of the CTU roller rig in the 2015 after more than two decades of modifications is depicted in Fig. 3. The rig is designed to carry out experimentation with a roller revolution range up to 700 min^{-1}, corresponding to the full scale vehicle speed of 230 kmh^{-1}. The CTU roller rig is not restricted to perform experiments only for a straight track, but it is capable also to simulate negotiation of a curved track, or track consisting of arbitrary number of straight, transition and constant curvature sections.

The increasing demands on experiments carried out and also the wear of the currently used test bogie instilled motivation for the design of a new test bogie which was designed, manufactured and put into operation in 2015 [14].

Fig. 4 shows the CTU roller rig with the new experimental bogie. This bogie does not correspond to any specific bogie of a real vehicle. Its design is based upon the goals of experimental research. In order to achieve a high geometrical precision, most of the parts are made of aluminium by CNC machining. In order to eliminate dry friction and clearances, connections of mutually movable components are realized by roller and linear roller type bearings. The wheelsets can be quickly setup to conventional or IRW type. Wheel profiles with different taper grade in range from 1/40 to 1/5 are available. The wheelsets are designed to accommodate individual wheel drives in the future.

Fig. 3. CTU roller rig in 2015

Fig. 4. The new test bogie at the CTU roller rig

The bogie has no primary suspension and the wheelsets can move only in the yaw direction towards the bogie frame. Each wheelset is independently actuated by an active controlled mechanism (Fig. 5). The actuator is a permanent magnet synchronous servomotor M408S (item 1) with rated torque 2.5 Nm. It can be controlled to the desired magnitude of yaw torque acting on the wheelset, or to a desired value of yaw angle between the wheelset and the bogie frame. The actuator torque is

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transmitted via the toothed belt (item 2) to a steering rod (item 3) and finally by two pairs of linkages (item 5) to the wheelset.

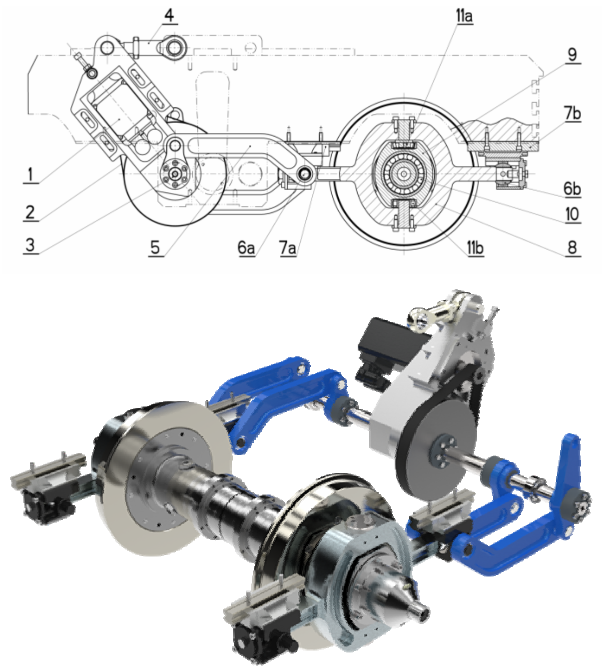

Fig. 5. Actuated wheelset steering mechanism

Findings

The CTU roller rig is utilized both for education and research purposes. Regarding education, the CTU roller rig serves not only to demonstrate fundamentals of railway vehicles running dynamics and to teach students measurement of various physical quantities, but students are also involved in the rig development. Many of its parts and subsystems were designed in lieu with student diploma works.

With regards to research, the CTU roller rig is utilized for projects focused on running dynamics of both conventional and IRW wheelsets and could be divided to the three main areas:

- Improvement of high speed stability.
- Improvement o curving behaviour.
- Improvement of guiding properties.

First two points relate mainly to the running gears with conventional wheelsets, whereas the third point concerns IRW. As an example two types of experiments are shown.

Radial steering of conventional wheelsets. To confirm roller rig capability for curved track simulations and to test system for wheel roller contact forces measurement, roller rig experiments focused on radial steering of conventional wheelsets were performed [13].

The simple control law was applied by setting required yaw angle between wheelset and bogie frame proportional to the radius of negotiated curve. Experiments with varying curve radii and varying yaw angles between wheelsets and bogie frame were performed. Influence of the wheelset yaw angle to the quasistatic mean value of lateral component of the wheel rail force (Y-force) was studied. Fig. 6 shows an example of Y-force time development obtained by one test run.

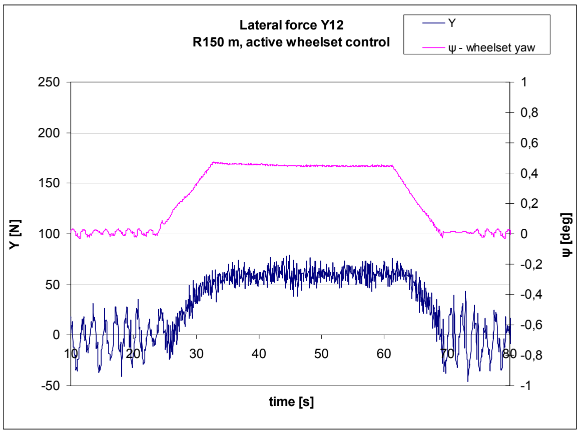

Fig. 6. Curve passing test at the roller rig – measured data ψ … yaw angle of the wheelset towards the bogie frame Y … lateral component of wheel roller contact force

In accordance with the CTU scaling strategy, the parameters of a virtual bogie were calculated. This virtual bogie is a full scale representation of roller rig test bogie. The MBS software Simpack was used to build a computer simulation model of the virtual full scale bogie and perform simulations of curve negotiation. The radius of the curve vas 150 m and the vehicle speed was set up to 35 km/h. To obtain similar conditions as we are able to simulate on the roller rig, the lateral acceleration was fully compensated by rail superelevation and the friction coefficient set up to 0.3. Different respective wheelset steering angles were set up and the mean value of Y-force on the outer wheel of the leading axle was observed.

Fig. 7 compares Simpack simulation results with the roller rig measurements. Considering the differences in a vehicle behaviour on a roller rig

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and on a track and scaling issues, the experimental and MBS model results show good agreement. The results confirmed possibility of curved track experiments on CTU roller rig and expected Y-forces reduction by actuated wheelset steering.

Fig. 7: Dependency of Y force mean values on yaw angle of wheelsets

Hunting motion stabilization by active controlled wheelset guidance. The concept of active control is based on adding sensors, a controller and actuators to the existing mechanical system. Sensors observe the system and provide the information about its current state to the controller. Based on sensors signals the controller computes driving commands for the actuators which then influence the system behaviour by applying corresponding forces or torques. It is generally agreed that by utilization of such system in a vehicle suspension superior properties over a conventional passive vehicle could be achieved.

Most of the experiments conducted at the CTU roller rig over the last several years were focused on utilization of active control in a primary suspension and wheelset guidance. Different control goals, control strategies, controller complexities and sensor instrumentations were tested. As an example the implementation of the «Active yaw damping» is shown [16].

Wheelset stabilization is commonly achieved by linking two wheelsets to the bogie frame via primary suspension. This stabilizes the wheelset but also deteriorates the curving performance. The demand of higher operating speeds usually requires stiffer primary suspension, whereas improvement in the curving performance requires primary suspension softening and vice versa. Thus a design of a railway vehicle running gear is always based on tuning suspension parameters and the inevitable compromising between curving performance and high-speed stability. Applying the «Active yaw damping» method, high speed stability can be achieved without deterioration of curving performance by increasing a yaw stiffness of the primary suspension. This method is based on introducing controlled yaw torque acting between a wheelset and a bogie frame. The torque value is proportional to the lateral velocity of the wheelset.

The system of active yaw damping was implemented as a functional test of the new experimental bogie [15]. Lateral positions of wheelsets were directly measured by contact position transducers, the output signal of which is sent to the analogue inputs of an I/O card installed in a standard PC. Then the signals were filtered, differentiated, and further processed to obtain wheelsets lateral velocities. All the signal processing is executed in a real time using Matlab Simulink software and its real time toolbox. The controller output is in the form of two voltage signals proportional to required actuator torques. Those signals are in a sampling rate of 200 Hz sent via analogue output of the I/O card to the analogue inputs of inverters, which control wheelset steering actuators.

Fig. 8 shows measured lateral positions of both wheelsets during a roller rig test. It can be seen, that once active yaw damping control is switched on (from 15 to 66 s) both wheelsets run in the centre of a track, whereas without active control wheelsets exhibit heavy hunting.

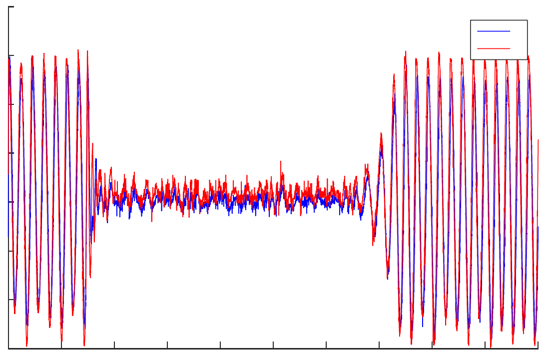

Fig. 8. Time development of wheelsets' lateral position

Originality and practical value

Active control employed throughout today's railway vehicles are mainly utilized in partial subsystems such as, drive control, wheel slide protec-

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tion, heating and ventilation, etc. The direct impact of electronics and control systems on the vehicle running dynamics is on railway vehicles in regular operation limited to the vehicles with tilting body and rare usage of semi-active dampers. In contrast to this, for aircrafts or motorcars, the electronics has fundamentally higher impact on basic functional properties. Practically each of today's military or passenger aircraft are equipped with so called «fly-by-wire» technology that fully controls flight dynamics. Also motorcars are commonly equipped with advanced drive-assistance electronic systems. This technological lead can be attributed to long-term operational life of railway vehicles in comparison to motorcars or aircrafts. It can be assumed that also on railway vehicles the utilization of the electronics and control concepts will increase with time. Further, the utilization of control concepts that directly influence running dynamics and interaction between the railway vehicle and the track can be expected.

Thus, scaled roller rig experiments plays an important role in the research of active control of railway bogies conducted at the CTU.

Conclusions

The CTU roller rig and its experimental bogie provide the possibility of laboratory tests featuring most of the applicable actuation schemes at the primary suspension and the wheelset guidance level. Besides standard displacement, acceleration, torque and force sensors, the bogie is equipped with measurement of forces between axleboxes and the bogie frame. Furthermore, Y forces measurement implemented on the rollers allows not only to study running dynamics of active controlled railway bogie, but also to test its influence to the magnitude of wheel-rail contact forces and consequent wear of the wheels and rails.

Despite the increasing accuracy and reliability of computer simulations, vehicle testing is still unavoidable part of the process of a vehicle development and homologation. Long term experience at the CTU shows that testing on a scaled roller rig is an outstanding way to verify computer simulations results without high costs. Despite of the technical and legislative issues the utilization of active controlled wheelset guidance is regarded as a promising design solution for the railway vehicles in the future. Research in this area is certainly not finished and CTU indeed plans to progress it further, where scaled-roller rig testing will definitely play a vital role.

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Я. КАЛІВОДА[1*], П. БАУЕР[2*]

[1*]Каф. «Автомобілі, двигуни внутрішнього згоряння та залізничний транспорт», Чеський технічний університет, факультет машинобудування, вул. Технічна, 4, Прага 6, Чеська Республіка, 16607, тел. +(420) 224 352 493, ел. пошта jan.kalivoda@fs.cvut.cz, ORCID 0000-0002-0278-2515
[2*]Каф. «Автомобілі, двигуни внутрішнього згоряння та залізничний транспорт», Чеський технічний університет, факультет машинобудування, вул. Технічна, 4, Прага 6, Чеська Республіка, 16607, тел. +(420) 224 352 493, ел. пошта petr.bauer@fs.cvut.cz, ORCID 0000-0002-0940-3303

СТЕНДОВІ КАТКОВІ ВИПРОБУВАННЯ В ЧЕСЬКОМУ ТЕХНІЧНОМУ УНІВЕРСИТЕТІ

Мета. Хоча досягнення в області технології комп'ютерного моделювання дозволяють отримати досить надійні результати моделювання, натурні випробування досі грають істотну роль у процесі розробки і сертифікації будь-якого залізничного транспортного засобу. З іншого боку, шляхові випробування залежать від погодних умов, їх важко організувати і вони не підходять для випробування транспортних засобів у критичних ситуаціях. На катковому стенді випробувальний транспортний засіб фіксується в поздовжньому напрямку, а замість залізничної колії використовуються обертові ролики. Таке пристосування дає можливість провести динамічні випробування ходових характеристик рейкових транспортних засобів у безпечному та стабільному лабораторному середовищі. Мета статті: дослідити та описати стендові каткові випробування на катковому стенді в Чеському технічному університеті (ЧТУ) в Празі. **Методика.** В статті показана історія розвитку масштабованого каткового стенду ЧТУ, починаючи з ранніх етапів і до поточних проектів, в яких використовується катковий стенд ЧТУ. Докладно описані діючі конструкції експериментального візка, каткового стенду, датчиків і приладів, а також типів експериментів, що проводяться на катковому стенді ЧТУ. **Результати.** Доведено недопустимість нехтування відмінностями в поведінці транспортного засобу на залізничній колії та масштабованої моделі на катковому стенді. Масштабовані випробування на катковому стенді є відносно недорогим способом для перевірки і демонстрації результатів комп'ютерного моделювання. Вони особливо корисні для перевірки моделювання багатомодульних систем (БМС) абсолютно нових концепцій ходової частини. **Наукова новизна**. Досліджено, що в даний час катковий стенд у ЧТУ використовується для випробувань із активним контрольованим керуванням колісної пари. Згідно з результатами моделювання, опублікованими в багатьох роботах, такі системи пропонують, в принципі, більш високу продуктивність у порівнянні зі звичайними пасивними транспортними засобами. Однак використання і тестування активного контрольованого управління колісної пари на транспортних засобах і раніше рідко зустрічалося. Катковий стенд ЧТУ служить в якості інструменту для перевірки комп'ютерного моделювання та демонстрації переваг активного управління колісної пари. **Практична значимість**. Випробування, проведені на катковому стенді ЧТУ, підтверджують можливість істотно впливати на динаміку ходу залізничного транспортного засобу за допомогою активного контрольо-

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ваного управління колісної пари. Така концепція може розглядатися в якості можливого і ймовірного підходу при розробці ходової частини майбутніх залізничних транспортних засобів.

Ключові слова: катковий стенд; активний контроль; управління колісної пари; мехатронний візок

Я. КАЛИВОДА[1*], П. БАУЭР[2*]

[1*]Каф. «Автомобили, двигатели внутреннего сгорания и железнодорожный транспорт», Чешский технический университет, факультет машиностроения, ул. Техническая, 4, Прага 6, Чешская Республика, 16607, тел. + (420) 224 352 493, эл. почта jan.kalivoda@fs.cvut.cz, ORCID 0000-0002-0278-2515

[2*]Каф. «Автомобили, двигатели внутреннего сгорания и железнодорожный транспорт», Чешский технический университет, факультет машиностроения, ул. Техническая, 4, Прага 6, Чешская Республика, 16607, тел. + (420) 224 352 493, эл. почта petr.bauer@fs.cvut.cz, ORCID 0000-0002-0940-3303

СТЕНДОВЫЕ КАТКОВЫЕ ИСПЫТАНИЯ В ЧЕШСКОМ ТЕХНИЧЕСКОМ УНИВЕРСИТЕТЕ

Цель. Хотя достижения в области технологии компьютерного моделирования позволяют получить весьма надежные результаты моделирования, натурные испытания до сих пор играют существенную роль в процессе разработки и сертификации любого железнодорожного транспортного средства. С другой стороны, путевые испытания зависят от погодных условий, их трудно организовать и они не подходят для испытания транспортных средств в критических ситуациях. На катковом стенде испытываемое транспортное средство фиксируется в продольном направлении, а вместо железнодорожного пути используются вращающиеся ролики. Такое приспособление дает возможность провести динамические испытания ходовых характеристик рельсовых транспортных средств в безопасной и стабильной лабораторной среде. Цель статьи: исследовать и описать стендовые катковые испытания на катковом стенде в Чешском техническом университете (ЧТУ) в Праге. **Методика.** В статье показана история развития масштабированного каткового стенда ЧТУ, начиная с ранних этапов и до текущих проектов, в которых используется катковый стенд ЧТУ. Подробно описаны действующие конструкции экспериментальной тележки, каткового стенда, датчиков и приборов, а также типов экспериментов, проводимых на катковом стенде ЧТУ. **Результаты**. Доказана недопустимость пренебрежения различиями в поведении транспортного средства на железнодорожном пути и масштабируемой модели на катковом стенде. Масштабируемые испытания на катковом стенде являются относительно недорогим способом для проверки и демонстрации результатов компьютерного моделирования. Они особенно полезны для проверки моделирования многомодульных систем (ММС) совершенно новых концепций ходовой части. **Научная новизна**. Доказано, что в настоящее время катковый стенд ЧТУ используется для испытаний с активным контролируемым управлением колёсной пары. Согласно результатам моделирования, опубликованным во многих работах, такие системы предлагают, в принципе, более высокую производительность по сравнению с обычными пассивными транспортными средствами. Однако использование и тестирование активного контролируемого управления колёсной пары на транспортных средствах по-прежнему редко встречается. Катковый стенд ЧТУ служит в качестве инструмента для проверки компьютерного моделирования и демонстрации преимуществ активного управления колёсной пары. **Практическая значимость**. Испытания, проведенные на катковом стенде ЧТУ, подтверждают возможность существенно влиять на динамику хода железнодорожного транспортного средства с помощью активного контролируемого управления колёсной пары. Такая концепция может рассматриваться в качестве возможного и вероятного подхода при разработке ходовой части будущих железнодорожных транспортных средств.

Ключевые слова: катковый стенд; активный контроль; управление колёсной пары; мехатронная тележка

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