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Testing of Railway Vehicles Using Roller Rigs

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Abstract

Roller rigs are laboratory devices enabling to study various phenomena in the field of railway vehicles dynamics and the wheel-rail contact. The main benefits of roller rig experiments are high controllability, repeatability and flexibility of experiment setup and usually also lower costs compared to the field tests. One of the goals of joint cooperation between the Czech Technical University in Prague, Czech Republic (CTU) and the Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Ukraine (DNURT) is to design, build, and finally to operate at the DNURT laboratory the new roller rig. The presented paper is an initial study prepared within the framework the joint project. It summarizes the possibilities of roller rig utilization for railway vehicles research and describes the main concepts of existing design solutions.

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1. Introduction

Research of dynamic characteristics of railway vehicles is relevant both at the stage of creating new designs of railway rolling stock, as well as at the stage of selecting the individual parameters of mechanical systems. Especially important is the determination of the dynamics and the wear of the wheels and rails in the study of the conditions of the rolling stock and the way of interaction. As is well known, the study of the dynamics of railway vehicles can be

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carried out theoretical and experimental methods, while, as a rule, the calculation results are verified by means of experiment. This is the case and checking the adequacy of mathematical models of spatial fluctuations of railway vehicles, and the direct study of construction of rolling stock. In this experimental researches conducted both on experimental designs rolling, and on physical models of these constructs in the laboratory on the bench equipment.

In scientific laboratories and Test center of Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan has many years of experience in research of railway rolling stock and industrial vehicles [1 - 5]. Over the last 30 years tested more than 300 types of new and modernized rail vehicles. By the tested objects include: freight and passenger cars, electric and diesel locomotives, electric trains (EMU) and rail buses, track machines and special railway rolling stock. As a rule, research is carried out by means of mathematical modeling and experimental. This makes it possible to estimate the largest number of options. But experiments are performed during acceptance tests or certification of rolling stock. In this experimental study carried out in field conditions, and on the stand equipment. Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan and the Czech Technical University cooperate in the field of improvement of experimental equipment. The first project concerns the creation of roller rig stand for bogies. And in the DNURT and CTU are roller rig stands. So, in DNURT has roller rig stand for real two axial freight car bogie, which can transmit the rotation of one wheelset and load the bogie vertical loads up to 50 tons. Features of the booth is limited, and therefore decided to create a new test of roller rig stand together with scientists from CTU.

Then a closer look at a retrospective of rolling stock testing stand equipment and improvement of roller rig stands.

2. Laboratory testing of railway vehicles

Track tests play an essential role in the process of new rolling stock approval. Each new type of vehicle must successfully undergo set of track tests prescribed by international or national regulations. On the other hand track tests are very expensive, time consuming and difficult to organize. 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 the safety requirements. Therefore, every railway vehicles manufacturer tends to minimize the amount of track tests and replace them by less demanding alternatives. Nowadays, the role of testing is being often replaced by computer simulations.

Despite the relatively high accuracy and wide availability of computer simulations, the testing of rail vehicles and their components is still an inevitable part of vehicle development. Substantial large portion of these tests can be conveniently carried out in a stable and controlled laboratory environment instead of on a track. A common part of vehicle development are static and dynamic structure tests, specific tests of brake systems, air-conditioning systems, electrical equipment, pneumatic equipment, and many other tests performed in a laboratory.

A specific category of tests are tests where forces in a wheel-rail contact should be applied. Because the vehicle and the forces in the wheel–rail contact interact, it is not possible to determine those forces in advance and then apply them on a vehicle during the test. To build the railway track in a laboratory is also not possible due to the size of railway vehicles. Laboratory simulation of wheel-rail contact is necessary. For this purpose specific devices called roller rigs are used.

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 laboratory testing of railway vehicles by roller rigs 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. In contrast with track tests, roller rigs offer also the advantages of lower cost, low spatial demands, and ease of access to components and the testing apparatus.

3. Roller rig testing – review of studies

The first known utilization of a roller rig for the investigation of the performance of steam locomotives was in United Kingdom in 1904 [6]. However, the most important era of roller rigs utilization came together with the development of high-speed vehicles. From the late fifties roller rigs in Japan, UK, Canada, USA, Italy, France, Germany, Korea, China, and other countries have been built [7]. Roller rigs are used for a wide variety of purposes in railway vehicles development and research.

3.1. Railway vehicle dynamics

The most common application of roller rigs is research of railway vehicles running dynamics. Roller rigs are used especially in cases where it is necessary to perform many experiments under specifically defined conditions or in cases where the vehicle is to be tested in extreme conditions, such as running at the derailment limit, when it is not possible to ensure the all safety requirements which are necessary for the track tests. Such situation occurred especially during the initial period of high-speed vehicles development, where roller rig testing played an essential role. Currently, roller rigs are used primarily for testing new vehicle concepts and new components in vehicle running gears that directly affect running dynamics and safety. Also the performance of suspension, brake, steering mechanisms and other systems is being investigated by roller rigs with less effort and cost compared with field tests.

3.2. Wheel–rail contact investigation

All forces between the vehicle and the track are transmitted via wheel-rail contact patches. The wheel-rail contact patches are relatively small, nevertheless they transmit considerable forces. A detailed description of the phenomena taking place in a wheel–rail contact is thus very complex, multidisciplinary problem which is being solved in many research institutes. The knowledge of these phenomena is very important for predicting the wear of wheels and rails and for building precise, robust and fast mathematical models to predict the creep forces between wheel and rail. Many studies focused on deeper understanding of physics behind the contact mechanics at the wheel-rail interface, measurement of adhesion and creep characteristics, validation or improvement of the existing contact theories, investigation of the surface damage mechanism of the wheel and rail, rail corrugation, curve squeal, characteristics of different third body-layers at the contact, and traction effort have been conducted utilizing advantages of roller rig testing.

3.3. Verification and validation of simulation models

The current trend in the research of railway vehicles dynamics and vehicles development tends to maximize the use of computer simulations and eliminate number of experiments. Computer simulations are regarded as quick, effective and unexpansive method. Compared to physical experiments they allow investigation of a large number of vehicle parameters in a wide range without inadequate effort. Utilization of computer simulations significantly reduces the time necessary for vehicle development and makes this process more effective. The parameters of vehicle and its components are designed and widely optimized using computer simulations. The testing is used, in the ideal case, just in order to verify the vehicle's properties and meet the legislative requirements of the approval process. Such approach requires an accurate, reliable and fast simulation tools. Roller rigs have played, and still play, an important role in the development of tools for building simulation models and their verification. A variety of mathematical models for different purposes have been developed and consequently tested and verified using roller rigs.

3.4. Other utilization

Besides above described activities roller rigs are also used as an educational tool [13]. They serve at many universities to teach students railway vehicle dynamics fundamentals or systems for measurements of various physical quantities. Another utilization of roller rigs is testing the roller rig design itself. For this purpose many scaled roller rigs have been built as an initial stage of full scale roller rig development.

4. Roller rig designs

Roller rigs designs vary significantly in accordance with the purpose and objective of performed experiments. Each roller rig is a unique device. The main criteria for distinguishing roller rig designs are:

1. Scale,
2. Tested specimen,
3. Design concept.

The scale divides roller rig into two main categories – full scale and scaled. Scaled designs offer several advantages such as much lower investments, lower cost of operation, lower energy consumption, lower space requirement, and easier implementation of parameter changes. However, instead of standard components or whole vehicles only scaled models could be tested. Moreover interpretation of results of scaled experiment is not straightforward and depends on the chosen scaling strategy [8].

According to the tested specimen the single wheel, wheelset, bogie and full vehicle test rigs are distinguished. The single wheelset setup significantly increases system complexity over the single wheel design, but offers several advantages especially the ability to study the interaction associated with a suspension setup and the dynamics of a single axle. Testing of an assembled bogie or a whole vehicle significantly increases a system complexity over both the single wheel and wheelset designs, but potentially offers many additional benefits, because bogie and vehicle rigs could be used for studying the railway vehicle as a complete system.

Various design concepts of roller rigs (Fig. 1) could be found. The simplest and most common of these is vertical plane roller concept (a). Other design concepts such as perpendicular roller (b), internal roller (c), or oscillating rail (d) concepts are usually designed for specific purpose and utilization of such concepts is quite rare compared to the standard vertical plane roller concept.

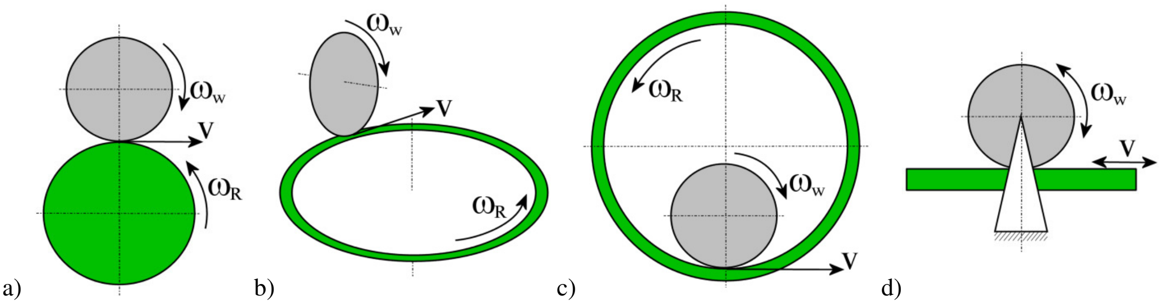

Fig. 1. Roller rig design concepts (a) vertical plane roller; (b) perpendicular roller, (c) internal roller, (d) oscillating rail.

4.1. Roller rigs for studying railway vehicle dynamics

Because a single wheel rigs cannot be used for hunting studies, minimum rig configuration for studying railway vehicle dynamics is a single wheelset rig. However the most common rigs in this field are full scale vertical roller rigs for testing whole vehicles. The first device of this kind was used in the beginning of the 20th century. During those first tests, growing intensity of lateral vibration while increasing the circumferential speed of the rollers, later called hunting motion, was observed. This phenomenon was considered very significant in terms of increasing operating speed on the railway and the utilization of roller rigs for railway vehicle running dynamics investigation have begun. The importance of these rigs has increased with the development of high-speed rail in the second half of the 20th century. The most advanced rigs of this type, such as DB roller rig in München-Freimann or roller rig of State Key Laboratory of Traction Power in Chengdu (Fig. 2), allow to be setup for varying vehicle dimensions, wheelset gauge, and loads, and simulate vehicle running up to speed 500 km/h for a wide range of track conditions including track irregularities and curved track. Tests on this kind of roller rigs came close to reality because full bogie or vehicle can be tested under conditions similar to a real track. However, the costs for building and operation of such devices are very high. Nowadays, in the field of vehicle development, the role of the full-scale roller rigs is being replaced by considerably cheaper computer simulations. Nevertheless, this type of roller rigs still play an important role in countries which started to develop their own fleet of high speed vehicles, such as China, whereas once a very important facility of this type in München-Freimann (Germany), Pueblo (USA) or Derby (UK) are already out of operation.

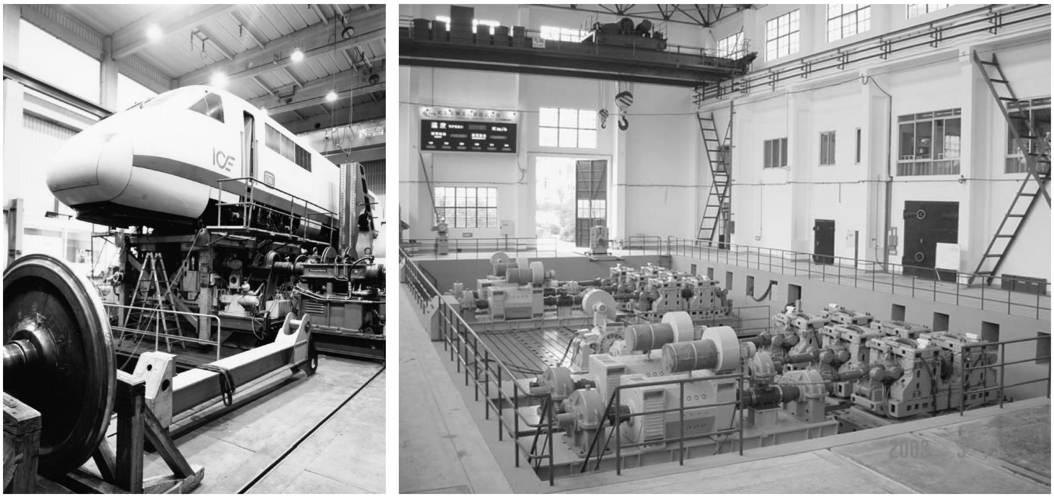

Fig. 2. The propulsion unit of one of the first ICE-trains on the roller rig at München-Freimann [6] (left)
The roller rig in Chengdu [7] (right).

Another test rig type, which is utilized for studying railway vehicles dynamics are scaled roller rigs, usually designed for 1/5 up to 1/3 scaled models of two axle bogies. Among major drawbacks of a scaled system are impossibility to directly test standard components and difficulties with an interpretation of a scaled experiment results in a full scale world. Utilization of a scaled roller rigs in the process of development of particular vehicle is thus substantially limited. Scaled roller rigs are typically built at universities or research institutions for development and testing of completely new running gear concepts for example active controlled drives of independently rotating wheels (Fig. 3, left), [9], active controlled wheelset steering (Fig. 3, right) [10], [11] or inverse thread wheelsets [12].

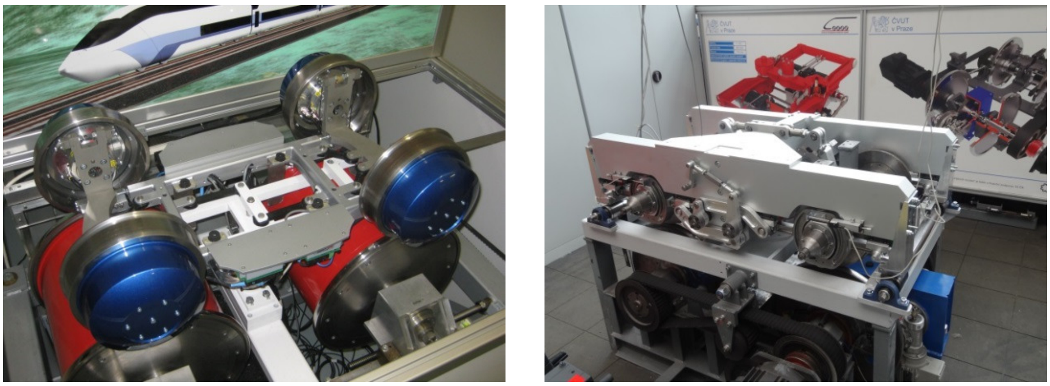

Fig. 3. Roller rig at DLR, scale 1/5 (left) Roller rig at CTU in Prague, scale 1/3.5 (right).

Specific category of scaled testing are test on scaled tracks. In case of scaling of 1/5 or more, the whole track consisting of a straight and one or two curved sections could be placed in a laboratory (Fig. 4) and then negotiation of such track by a model of a vehicle can be studied.

Fig. 4. Test vehicle with power steering railway bogies with independently rotating wheels at Chiba Experimental Station, University of Tokyo, scale 1/10 [19] (left), Active steering vehicle at KRRI research testbed, scale 1/5 [20] (right).

4.2. Roller rigs for wheel–rail contact investigation

Studying phenomena in a wheel–rail contact requires precise positioning of a wheel and roller, precise control of wheel and roller speed and precise control of wheel loading. Complex design of a bogie increases the difficulty to fulfill those requirements. Therefore roller rigs for wheel-rail contact investigation are usually in a form of single wheel on roller or wheelset on rollers. Both full scale and scaled rigs are used (Fig. 5).

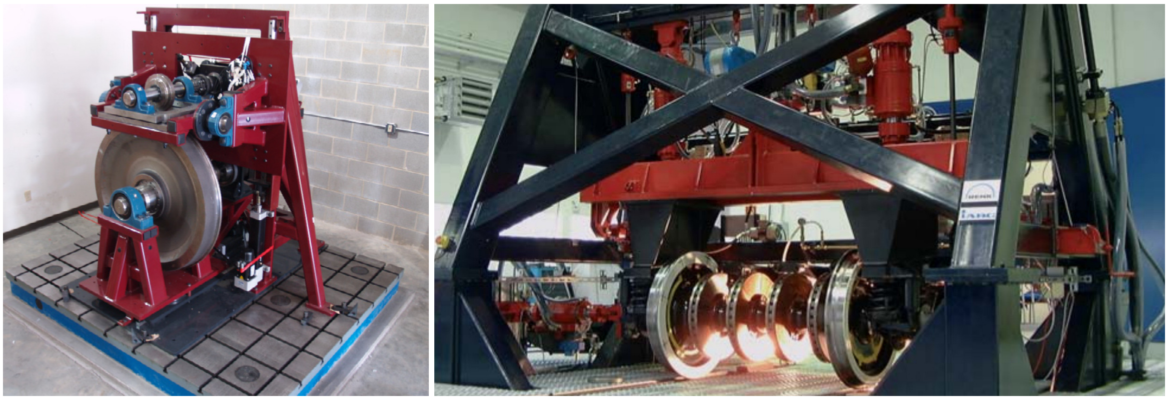

Fig. 5. The Virginia Tech Roller Rig, scale 1/5 [14] (left) DB Systemtechnik wheel-on-roller test rig, full scale [16] (right).

The investigation of wheel–rail contact phenomena requires simulation of contact point parameters as close as possible to the track conditions. The finite roller diameter causes the inevitable errors between wheel–rail and wheel–roller contact. Besides standard vertical roller rigs also inner roller or horizontal roller concepts are used (Fig. 6, left), because such concepts allow error reduction by increasing the roller diameter, and keeping the overall rig dimensions certain limits at the same time. Specific type of test rig type is oscillating rail rig (Fig. 6, right). Such rig is specifically used for testing of rails, switches, and other track components.

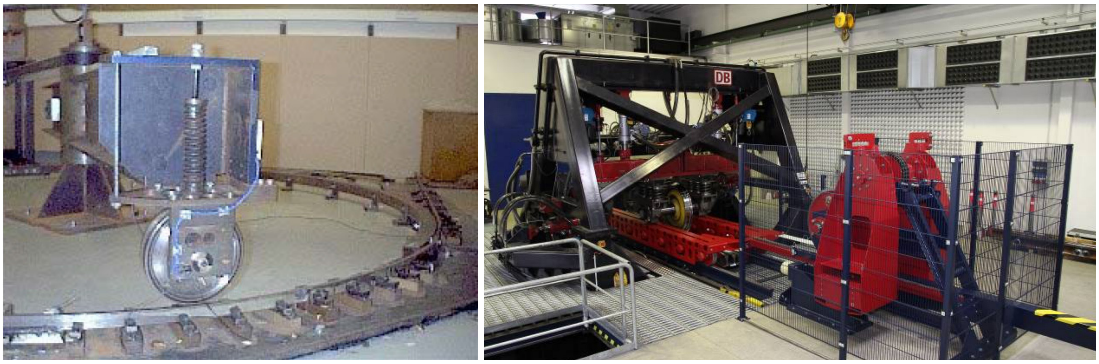

Fig. 6. ISVR wheel-rail rolling rig, scale 1/5 [15] (left), DB Systemtechnik wheel-on-rail test rig, full scale [16] (right).

4.3. Roller rigs for verification and validation of simulation models

Scaled bogie roller rigs are usually used for validation of simulations models and development of computer codes. The main reason is possibility to test complex bogie on one hand and relatively low cost on the other. With the support of roller rig experiment several “in house” simulation models [17], [18], or commercial computer codes have been developed.

5. Conclusions

The main objective of the roller rigs is performing of different studies focused on railway vehicle running dynamics and wheel–rail contact mechanics without using a dedicated track. The main benefits of roller rig testing compared to the field test are high controllability and flexibility of experiment setup. The goal of presented paper is not to describe all the possibilities of roller rigs utilization and design concepts in detail, but to demonstrate very high variety of roller rig designs. Each roller rig design is unique and depends strongly on the goals of experiments. Because no roller design concept is winning, generally applicable solution, it is necessary to precisely define the goals of research activities and according them to design a test rig.

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