



DEVELOPMENT OF METHODOLOGY FOR CALIBRATION OF AN INERTIAL BRAKE TEST STAND

Ivana Domaniková, Miroslav Blatnický, Patrik Slušňák, Kateryna Kravchenko
University of Žilina, Slovakia

Abstract

Rail transport represents a key component of the transportation system in many countries, not only in Europe but also worldwide. Reliable and, above all, safe railway transport requires the use of transportation means, i.e. rail vehicles, whose operation is safe under all operating conditions. A fundamental factor influencing the operational safety of rail vehicles is the use of reliable braking systems, in particular their frictional interfaces, which enable the conversion of kinetic energy into thermal energy. At present, science and research focused on the braking and running characteristics of rail vehicles constitute highly important tools for the investigation and prediction of phenomena related to this field. Such research activities may be carried out directly during vehicle operation or under laboratory conditions using specialized test rigs. One such brake test bench is located in the heavy laboratory of the Department of Transportation and Handling Machines (further referred to as DTHM) at University of Žilina and represents one of only a limited number of approved specialized UIC brake test facilities in Europe. In terms of its application, the test bench is intended for the international certification of braking components of railway vehicles, including both disc brake linings and block brake shoes. In other words, the DTHM test bench represents a testing facility accredited by the Brake Test Benches Commission of the International Union of Railways (UIC). This accreditation applies to two types of brake tests aimed at homologation of brake pads in accordance with UIC 541-3 and brake shoes in accordance with UIC 541-4. The preparation of the measurement process, as well as the measurement process itself, is carried out in accordance with the relevant standards, such as EN 15328, and established operating procedures. One of the main stages of the measurement process preparation is the calibration of the inertial brake test bench, which represents a fundamental and initial step in the overall preparation procedure. Thorough analysis and proper preparation of all components of the measurement process conducted on the inertial brake test bench significantly influence the results obtained from the measurements. The primary purpose of calibration is to adjust the constants of the tangential force sensor so that the sensor readings correspond as closely as possible to the actual applied load.

Keywords: experimental test, test bench, rail vehicles, brakes

1 Introduction to problem statement

The investigation of rail vehicles in terms of their running dynamics as well as braking performance represents an important process in the search for appropriate and correct technical solutions by railway experts in cooperation with universities and industry specialists. Such research may be conducted directly during the operation of the investigated vehicles or carried out in laboratories equipped with test benches, which are capable of reproducing real operating conditions to a significant extent [1].

Worldwide, there are several test benches dedicated to the investigation of brake materials, bogie characteristics, as well as the properties of railway wheelsets. In addition, these test facilities play an important role in the identification of various types of damage or failures [2, 3]. Test benches related to rail vehicles can be classified as friction test benches, focused on the investigation of friction pair properties at the contact interface (between the railway wheel and the brake shoe or between the brake disc and the brake lining), or as dynamic test benches, whose function is to investigate the behavior of the entire vehicle as well as its individual components [4]. Dynamic test benches address similar research objectives as friction test benches; however, they are also used to study phenomena occurring at the wheel–rail contact interface, both in straight-track operation and in curved-track conditions [5]. On friction test benches, approval tests of brake components (brake shoes or brake linings) are performed in accordance with UIC 541-3 (for disc brakes) and UIC 541-4 (for block brakes), as well as durability tests of braking components and the determination of limiting braking power values. On dynamic test benches, it is possible to monitor, for example, wheelset vibrations, longitudinal slip occurring between the wheel and the rail, vertical contact loads, as well as rolling speed and rolling angle [6].

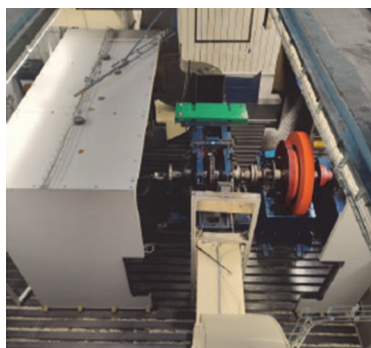


Figure 1 Certified inertial brake test bench of the mentioned laboratory

In the field of testing and measurement, test benches represent fundamental equipment for manufacturers and testing engineers. Test benches function as mobile testing laboratories mounted on a structural frame and typically comprise one or more force or torque sensing components, software, data acquisition instruments, and additional accessories. Force test benches are generally either motorized or manually operated. Motorized test benches, also referred to as mechanical or electromechanical test benches, offer the advantage of performance control through various operating modes, such as speed, cycle count, and test duration. More advanced test benches are frequently employed in applications requiring repeated high-performance testing, as well as for the verification of accuracy and quality. A wide range of testing equipment and sensors is used as part of the overall testing process [7, 8]. At present, several test benches in Europe are dedicated to the process of international certification of railway brake linings, including both block brake and disc brake systems. Moreover, the continuously increasing performance requirements imposed on braking systems of rail vehicles are accompanied by growing demands on the corresponding test benches. The need for innovation and continuous improvement is therefore of critical importance in this field. The primary driving factors include higher operating speeds, increased vehicle masses, and enhanced requirements for measurement and data evaluation accuracy [9]. The inertial brake test bench located in the DTHM laboratory (figure 2) consists of a mechanical chain and a measurement-control chain. The primary component of the mechanical chain is the brake station equipped with braking units. This station captures the braking torque during the braking process.

The measurement and control chain represents an essential system of the brake test bench. It comprises hardware components and software equipment. Its main functions include measurement, control of the braking process with respect to predefined parameters (ensured by a computer that programmatically controls the operation of the driving electric motor and the electropneumatic valve), recording of measurement data, and their evaluation. In addition, the system also provides processing of the obtained measurement results in graphical form [10].

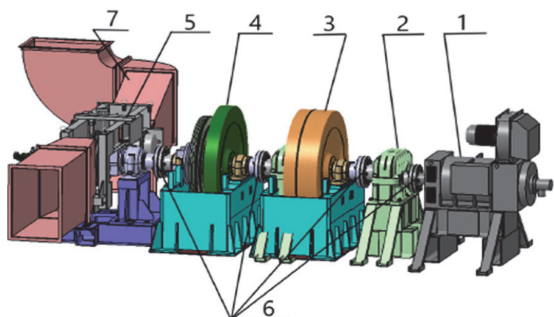


Figure 2 Concept of the brake test bench

Figure 2 illustrates the structural arrangement of the individual components of the mechanical chain of the DTHM brake test facility, with the individual positions referring to: 1 – main drive electric motor, 2 – gearbox, 3 – adjustable flywheel disc, 4 – fixed flywheel, 5 – brake station, 6 – couplings, 7 – air-handling system. In order to obtain relevant results, the brake test bench is equipped with an air-handling system and a water-spraying device to simulate weather and operating conditions of the system as realistically as possible. The test laboratory in which the brake test facility is installed is equipped with a sprung steel grating. At present, the brake test bench is primarily used for the certification of brake linings from various manufacturers, such as Puran and Knorr-Bremse. However, the primary focus of this work is the preparation of the measurement process and the activities associated with it. The first step in the calibration procedure is the measurement of the distance between the tangential force sensor and the axis of rotation of the brake test bench frame.

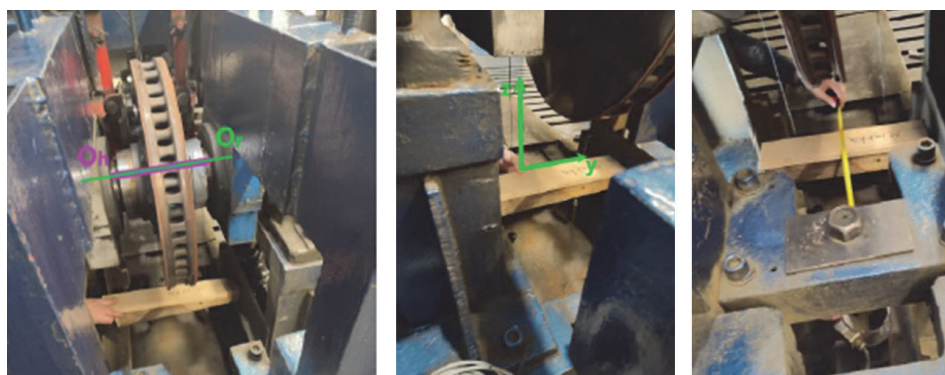


Figure 3 Measurement of the distance between the tangential force sensor and the axis of the rotation of the brake station frame: left – lowering of plumb lines along the shaft edge, center – detail of the prism positioned against the plumb lines, right – measurement of the distance from the sensor edge to the plane defined by the plumb lines

For accurate measurement of this distance, it is possible to use the fact that the axis of rotation of the frame (green color in figure 3, left) coincides with the axis of the brake disc shaft (purple color in figure 3, left). By suspending two plumb lines over the edge of the shaft, a reference plane is created (indicated in green in figure 3, center) that defines the measured distance from the sensor. After stabilization of the plumb lines, a planed prism is placed against them to facilitate the measurement, and the distance from the edge of the sensor to the plane defined by the plumb lines (i.e., to the edge of the prism) is measured (figure 3, right). Since both the shaft diameter and the diameter of the tangential force sensor are known, the shaft radius is subsequently subtracted from the measured distance of the tangential force sensor from the axis of rotation of the frame, and the sensor radius is added. This relationship, derived from the schematic shown in figure 4, can be mathematically expressed by equation (1):

$$a = x_m - r_h + r_s \quad (1)$$

where a – denotes the lever arm of the reaction force F_t – i.e. the distance from the center of rotation of the frame to the axis of the tangential force sensor (mm), $x_m = 598$ mm is the measured distance from the edge of the sensor to the plane defined by the plumb lines (mm), $r_h = 75$ mm is the radius of the shaft on which the brake disc is mounted (mm), $r_s = 45$ mm is the radius of the tangential force sensor (mm).

The individual geometric parameters shown in figure 4 are defined as follows: a - represents the distance of the reaction force captured by the sensor from the center of rotation of the disc. The distance b - denotes the force lever arm measured from the center of rotation of the brake test bench frame to the line of action of the force generated by two sets of calibration load plates with different masses m_1 and m_2 . As an illustrative example, the distance of the reaction force from the center of rotation of the disc was determined. After substituting the values into equation (1), a value of $a = 568$ mm was obtained. Subsequently, using a square positioned against the U-beam, the distance from the bearing housing to the edge of the U-beam was measured on both sides of the brake station (figure 5). Since the distance from the edge of the U-beam to the center of rotation of the frame was also required, half of the width of the bearing housing was added to the measured distance. The arithmetic mean of the values obtained on both sides of the brake station was then used as the reference distance at which the calibrated weights (plates) were applied.

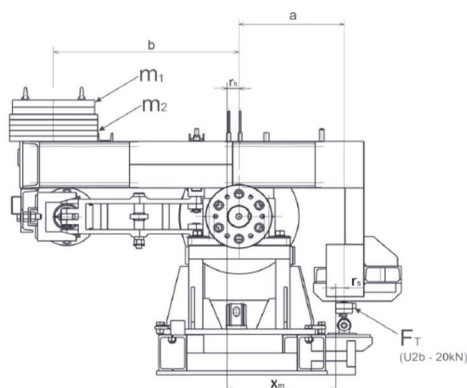


Figure 4 Calculation scheme of the brake station for determination of the tangential force F_t

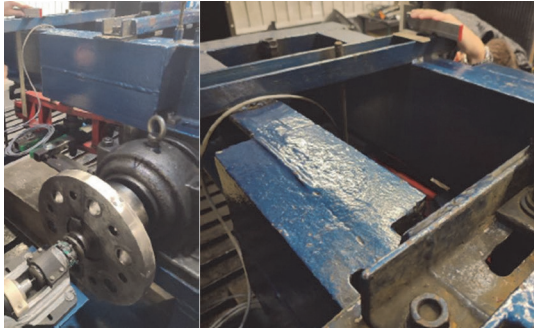


Figure 5 Measurement of the distance from the bearing housing to the edge of the „U“- beam edge: left side (left), right side (right)

2 Materials, methods and results

The resulting lever arm (distance) at which the gravitational loading force of the calibration plates (denoted as m_1 and m_2 in figure 4) acts is obtained by adding the distance of the plate's center of gravity from its edge. This value is known for both types of calibration plates used and remains constant. This dimension is implemented as a constant in the developed Excel file, thereby eliminating the need for repeated analytical calculations, which are replaced by the program. The file (program) then serves as a calibration protocol. The following input quantities can be entered into the Excel file:

- measured dimensions based on which the exact force lever arms are calculated— b , representing the force lever arm from the center of rotation of the frame to the center of gravity of the applied calibration weights, and the second force lever arm a , defined as the distance from the center of rotation of the frame to the axis of the tangential force sensor
- the exact mass values of the loading plates used in the calibration process; these weights are numbered and always applied in the same sequence, from which the acting force F_i is then calculated
- the force measured by the tangential force sensor— denoted as F_{s0} in the Excel file (the initial value is approximately 2.4 kN), represents the gravitational load exerted by the frame on the sensor. This initial value is subsequently subtracted from the other measured values.

The Excel file therefore contains formulas that allow the determination of the force acting on the sensor. This force is generated by the mass of the calibration loading plate. The resulting theoretical value is then compared with the force value measured by the sensor. Based on this procedure, percentage deviations are calculated and, if necessary, the sensor constant is adjusted to achieve the best possible agreement between the measured and calculated values. Once the required distances have been measured and recorded, and the load determined by calculation without any additional applied weights, the calibration process itself is initiated by sequentially placing individual loading plates onto the frame of the brake test bench. After each loading plate is applied, the force value indicated by the tangential force sensor is recorded again. During this loading procedure, the process continues up to the full measurement range of the sensor. The primary elements of the calibration process are the loading plates (figure 6), which are placed at a designated position on the brake station of the inertial brake test bench. The plates are available in two variants with different masses.

The first variant consists of a green-colored loading plate with a mass of 122 kg (figure 6, green) and dimensions of 120 × 47 × 3 cm, while the second variant is a red-colored plate with a mass of 155 kg and dimensions of 125 × 44 × 4 cm. Both variants are available in a quantity of four units. As previously mentioned, during calibration it is verified if after each individual loading plate is applied, the measured force remains within the permissible tolerance limits, i.e., does not exceed the value of 20 kN.



Figure 6 Calibration loading plates

The values measured by the sensor are therefore compared with the recalculated theoretical values based on the known masses and force lever arms to determine the deviations between the actual load indicated by the sensor and the calculated force. Subsequently, the sensor constant is adjusted as required. This constant defines the relationship between the sensor output voltage and the displayed force; for example, at an output of 2 mV/V the sensor indicates a force of 20 kN. The sensor constant is adjusted so that the sensor output values correspond as nearest as possible to the calculated values. Thus, the original calibration constants may be defined, for example, as 0 mV/V = 0 kN and 2 mV/V = 20 kN, whereas the adjusted calibration constants may be 0 mV/V = 0 kN and 1.935 mV/V = 20 kN.



Figure 7 Documentation image of the measurement and calculation software

Adjustment of the sensor constant must be performed with the frame fully loaded (i.e., with all weights applied) in order to obtain a value that most closely represents the actual operating condition. Subsequently, the entire calibration procedure – consisting of sequential loading of the individual weights – is repeated to verify if the sensor settings are satisfactory. The calibration is repeated primarily because adjustment of the sensor constant also slightly affects the initial force value measured under unloaded frame conditions. After adjustment of the constant, it is verified that all measured force values fall within the specified tolerance range. The overall calibration procedure thus exhibits an iterative character, progressively converging toward an optimal calibration state.

3 Conclusion

The data obtained during the calibration process are monitored and verified on the computer workstation using the developed measurement and calculation software (figure 7). Force measurement is performed using strain-gauge sensors. Correct placement of the loading plates at the designated position on the brake test bench is ensured and supervised by authorized personnel, while handling of the loading plates is carried out using a heavy-duty overhead crane with a lifting capacity of 12, 500 kg, operated by a trained operator. After the correct placement of the plates and completion of the calibration of the brake test bench, subsequent activities related to measurements on the inertial brake test bench are carried out. The described procedure for placing the plates onto the brake test bench is also performed in reverse when the loading plates must be removed from the brake test bench and stored at a designated location, again the handling is ensured with the overhead crane.

Funding

This research was supported by the Slovak Research and Development Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic VEGA 1/0037/25 “Research of the Properties of the Structural Design of a New Type of Unconventional Mechanism Implementable in Light Road Vehicles with a Self-locking Effect when the Torque Differential of the Driving Axle Wheels is Required”.

References

- [1] Kurčík, P.: Paking Brake Design for Test on UIC Brake Bench, 4th International Conference on Current Problems in Rail Vehicles, University of Žilina - PRORAIL 2019, pp. 399-408, Žilina, Slovakia, 17-19 September 2019.
- [2] Deshpande, V., Karekar, A.A., Patil, T., Shahapurkar, S., Hubalikar, P.: Design and Fabrication of Efficient Material Transport Equipment, International Research Journal of Engineering and Technology (IRJET), 4 (2017), pp. 2075-2081
- [3] Telek, P.: Computer Design of Materials Handling Equipment, The Publications of the MultiScience - XXIX, microCAD International Multidisciplinary Scientific Conference, Miskolc, Hungary, 2015.
- [4] Kim, M.S.: Dynamometer Tests of Brake Shoes under Wet Conditions for the High Speed Trains, International Journal of Systems Applications, Engineering and Development, 5 (2011), pp. 143-150
- [5] Wasilewski, P.: Full-Scale Dynamometer Test of Composite Railway Brake Shoes - Study on the Effect of the Reinforcing Fibre Type, Acta Mechanica et Automatica, 12 (2018), pp. 204-208
- [6] Pugi, L., Rosano, G., Viviani, R., Cabrucci, L., Bocciolini, L.: Modeling, Testing and Validation of Vibrational Behavior of Railway Brake Dynamometric Rigs, World Journal of Engineering, 21 (2024), pp. 425-442
- [7] INTERFACE, Test Stand Applications for Force and Torque, <https://www.interfaceforce.com/test-stand-applications-for-force-and-torque/>
- [8] Gu, T., Yuan, S., Gu, L., Sun, X., Zeng, Y., Wang, L.: Research on dynamic calibration and compensation method of strain-gauge type force sensor, Sensor Review, 44 (2024), pp. 68-80
- [9] UNION INTERNATIONALE DES CHEMINS DE FER (UIC), UIC B 126/RP 49: 2016. Braking issues: Synthesis report on the 8th edition of Leaflet 541-3 „Disc brakes“, Provisional report subject to approval and possible amendments by UIC SET 7
- [10] Gerlici, J., Lack, T., Harušinec, J.: Rail vehicles brake components test stand RAILBCOT constructional solution, 4th International Conference on Current Problems in Rail Vehicles, University of Žilina – PRORAIL 2019, pp. 159-170, Žilina, Slovakia, 17-19 September 2019.

