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DYNAMIC TESTING OF INNOVATIVE RAILWAY BRAKE SYSTEM FOR FREIGHT WAGONS

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Abstract: In this paper is shown dynamic testing of innovative railway brake system for freight wagons. Brake systems have the essential function of decelerating and stopping of railway rolling stock. Because the brake systems are a subject of large static and dynamic loads in external conditions, lot of tests should be done. In this paper will be shown the way of conducting dynamic testing on the innovative railway brake system.
Keywords: railway, dynamic, testing, brake, freight wagon

1. INTRODUCTION

The development of rail transport in recent decades goes in direction of increasing the speed and loading performance of the railway vehicles. This directly affects the development of brake technology [11]. The braking system has an essential function of reducing the speed and braking of the vehicle for the minimum possible time. The braking process of rolling stock is of great importance for the safety in the railway traffic. As railway operators focus on the need for greater improvements in efficiency and safety, there is still a significant need to advancements of the railway brake systems [12].
Several types of brake systems are used in the railways. Most commonly are used compressed air brake systems, called pneumatic brake systems [2]. Tread brake system is a type of mechanical (pneumatic) system that is most commonly used in freight wagons. In this type of system, braking is achieved by applying brake force between the brake shoes and the tread of the wheel, which is in rolling contact with the rail.
Over the last twenty-five years, there has been increased efforts for development and research of rail vehicles [8]. The researchers focused on achieving better performances, improving stability in curvature, driving comfort, and other factors in the dynamics of the rail vehicle. Also, the interest in monitoring the working conditions of railway vehicles is growing greatly [1]. Some solutions focus on wagons and their components, while others focus on the size of the transported goods. Considering that there is a potential danger for derailment of the wagon when braking, research is very important to analyze the impact of braking on the longitudinal and lateral dynamics of the wagons [6, 13, 14]. By increasing the speed of the railway vehicles, a key factor is to provide the necessary dynamic characteristics of the freight wagon which will enable safe movement in all possible conditions [3].
The complexity of modern rail wagons requires an extensive research of the wagon dynamics in the early stages of their development. The movement of rolling stock on the rail is one of the most complex dynamics systems in engineering [9]. It has many degrees of freedom and therefore studying the dynamics of rail vehicles is a complex matter. An important task in modeling the dynamics of railway vehicles is the proper development of the computation scheme and spatial mathematical model of the vehicle [5]. The dynamic testing is one of the most important validation tests to be done on brake systems.

2. MODEL OF BRAKE SYSTEM

— Types of brake systems

From a technical point of view, there are two main groups of brakes for rail vehicles: adhesion and non-adhesion brakes (Figure 1).
Adhesion brakes include: mechanical brakes and dynamic brakes. Mechanical brakes are divided into tread brakes and disc brakes. On disc brakes, the disc can be axle-mounted or wheel-mounted. Dynamic brakes include: rotating eddy current brakes, electrodynamic brakes and hydrodynamic brakes.

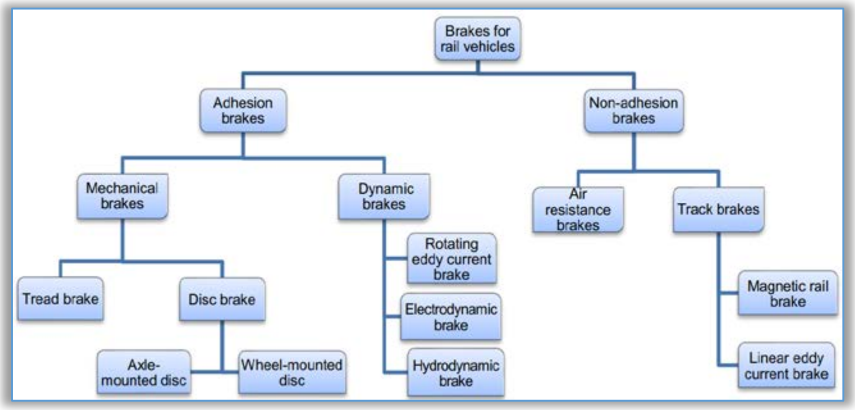

Figure 1. Types of brakes for rail vehicles [4]

Non-adhesion brakes include: air resistance brakes and track brakes. The second type of brakes includes: magnetic rail brakes and linear eddy current brakes.

Brake systems for rail vehicles can also be classified according to the activation method in the following categories:

- Pneumatic brakes.
- Electrodynamic brakes.
- Mechanical brakes.
- Electromagnetic brakes.

Pneumatic brakes can be classified into two types:

- Vacuum brakes.
- Compressed air brakes.

From all these braking systems, the focus in this paper is placed on pneumatic tread brake systems with compressed air.

— Model of innovative brake system

As railway operators focus on the need for greater improvements in efficiency and safety, there is a significant need for improvements of the brake systems [10]. Advanced brake systems lead to many benefits like improvements in the load capacity, increasing the safety and optimized life cycle costs.

The proposed model of the innovative brake system IBB 10 is intended for use in freight wagons and has the lowest weight on the market. It consists of a brake cylinder which through a system of levers and slack adjusters, transfers the force on the brake shoe holders and onto the brake shoes that come in frictional contact with the wheels of the wagon. The brake force is achieved through the brake cylinder and multiplied through the levers. Two slack adjusters serve to compensate the wear of the brake shoes and wheels. This brake system design allows easy assembly and disassembly on each sub-assembly separately, which is a great advantage in maintenance and repair of the system. The innovative IBB 10 brake system can be fitted between the wheels of a bogie type Y25 or similar and it fits the standard built-in measures as the conventional brake system. The function of the innovative brake system is to provide approximately equal brake force on all four wheels at the same time. The design is characterized by the use of a brake cylinder with (or without) a hand brake and two slack adjusters for automatic adjustment of the gap between the wheels and brake shoes.

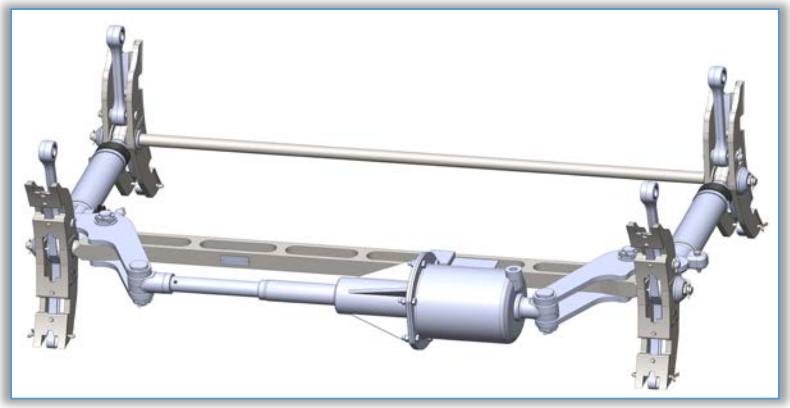

Figure 2. Model od innovative brake system IBB 10 without hand brake [10]

In Figure 2 is shown the innovative system IBB 10 without hand brake. This model of the innovative IBB 10 system is the base for all other variants.

The service brake force is calculated according to the following equation (1):

$$F = (p \cdot S \cdot 10 - F_B) \cdot i \cdot \eta - F_S \text{ (N)} \tag{1}$$

where are: p - brake cylinder pressure (bar); S - effective piston area (cm^2); F_B - return spring force (N); i - lever ratio; η - efficiency; F_S - slack adjuster counterforce (N).

From all the listed factors that influence the service brake force, only the brake cylinder pressure is a variable, while all other factors are constant. Taking into account the fact that for different types of freight wagons a different brake force is needed and the value of the pressure p is defined according to the UIC standard, from design point of view the ratio of the levers i can be changed.

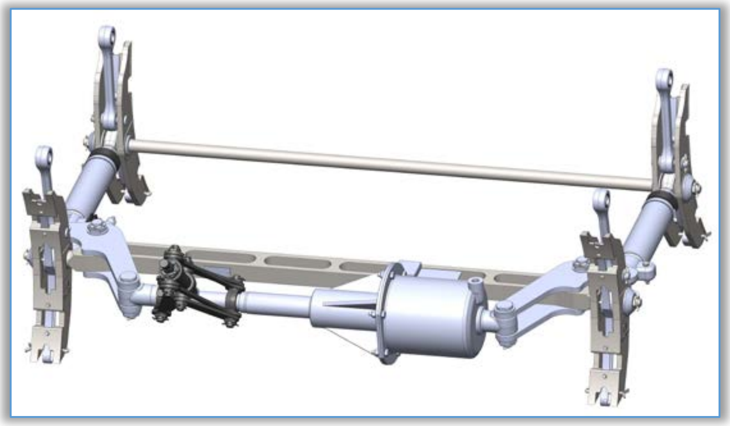

Figure 3. Model od innovative brake system IBB 10 with platform hand brake [10]

The innovative brake system IBB 10 is installed on one bogie, and since one freight wagon usually has two bogies, in most cases, two IBB 10 systems will be installed per wagon as a set. Because each freight wagon should have a parking option when is removed from the train composition (or because some other reasons), at least one IBB 10 unit must have a parking hand brake. In Figure 3 is shown a variant of the innovative brake system IBB 10 with a platform hand brake. This brake system with platform hand brake has the same function as IBB 10 without hand brake, but with added function of the hand application of a parking brake. The application of the platform hand brake is done from the platform of the wagon.

The activation of the platform hand brake should be performed from the platform of the freight wagon by turning the hand wheel through a gearbox and a telescope cardan shaft which is connected with the spindle of the platform hand brake mechanism. In Figure 4 is shown a model of Y25 bogie with installed brake system IBB 10 with platform hand brake and connecting components for activation with segment of the wagon platform. By turning the hand wheel, the torque is transmitted through the gears and the cardan shaft to the spindle of the platform hand brake mechanism activates (extends) the brake cylinder. This mechanism is connected to the piston rod and during service brake it moves together with the piston rod. The connection of the hand brake to the platform is necessary to be performed with a telescope cardan shaft in order not to decrease the degrees of freedom of the brake system during braking and releasing.

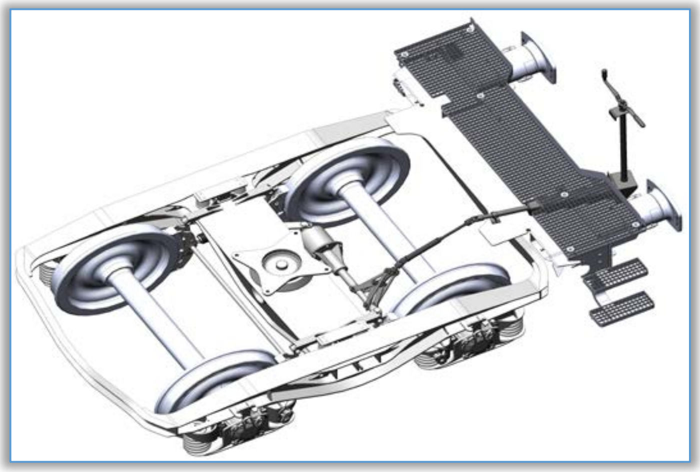

Figure 4. Model of Y25 bogie with installed brake system IBB 10 with platform hand brake and connection components for activation with segment of the wagon platform

3. DYNAMIC TESTING OF INNOVATIVE BRAKE SYSTEM

Due to the different variants of the IBB 10 brake system, dynamic testing should done on the most critical variant. In this case it is the innovative brake system IBB 10 with platform hand brake. The vibration test is performed according to the international standard IEC EN 61373: 2010, while the shock test is carried out according to IEC EN 60068-2-27.

According to IEC 61373 and the given deviations, the vibration and shock tests have to be performed in respect to the mounting position of the device under test, as a single axis excitation test:

≡ *Initial tests:*
  - Prior to any mechanical test, the principal functionality of the brake system has to be tested. This is done by visual inspection and execution of the initial performance test.
  - The frequency response function (FRF) of the IBB 10 has to be measured, when using vibration excitation with the test amplitudes of the functional random test.

≡ *Functional tests under vibration*: Throughout the functional test the IBB 10 is tested under random vibration excitation at levels similar to vibration levels appearing under normal operation. Throughout these tests each of duration less than 10 minutes, the brake action has to be applied five times, each brake action with 1,0 bar of brake cylinder pressure, holding this condition for about 5 seconds and releasing after that.

≡ *Simulated long-life test*: To simulate long life performance of the equipment, increased random vibration levels are applied to the device under test for a duration of 5 hours for each direction. The functionality of the device does not need to be evaluated throughout the simulated long life test.

≡ *Shock tests*: Five positive and five negative shocks of level (150 m/s^2), defined duration and shape, have to be applied to the device under test for each excitation direction.

≡ *Functional tests after vibration and shock tests*:
  - Leakage on 0,7 bar of pressure.
  - Leakage on 3,8 bar of pressure.
  - Brake force test on 3,8 bar of pressure.
  - Gap test.
  - Minimum position test.
  - Maximum position test.
  - Hand brake force test.

≡ *Final measurements*:
  - FRF of the IBB 10 has to be measured after all vibration tests, with vibration excitation of amplitudes as specified for the functional test.

- After passing all mechanical tests regarding vibration and shock application, the principal functionality of the IBB 10 has to be tested again. This is done by the execution of the final performance test (brake action applied five times, each brake action with 3,8 bar of brake cylinder pressure, holding this condition for about 5 seconds and releasing after that) and a following detailed visual inspection.

In order to perform dynamic testing on the IBB 10 brake system, it is necessary to assemble the brake system on a special test bench, which simulates the behavior of the bogie in a real field application. The special vibration test bench was developed by Awotec GmbH - Bad Vöslau for the needs of Wabtec MZT - Skopje, and the dynamic testing of the innovative IBB 10 brake system was done in cooperation with TU Graz from Austria. The mounting positions of the innovative braking system IBB 10 with the test bench are the same points of connection to the bogie in field. Figure 5 shows a shematic view of the vibration test bench with the innovative IBB 10 brake system with explanation of the mounting positions. The basic connection is via 4 hangers.

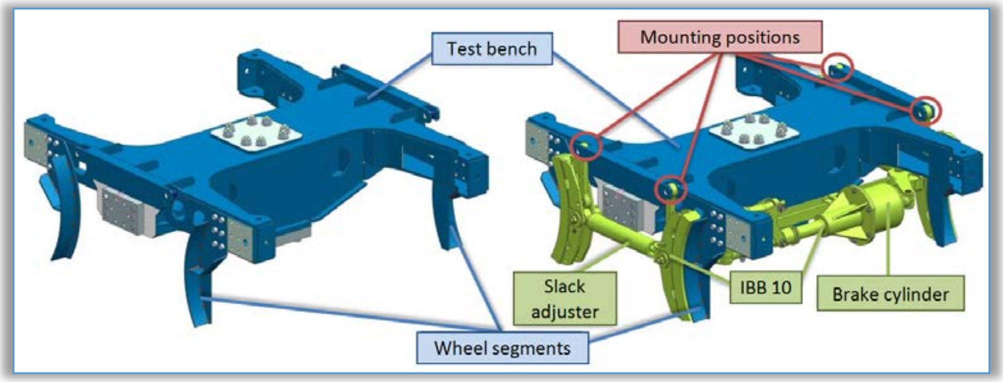

Figure 5. Shematic view of the vibration test bench with IBB 10 [7]

The orientation and mounting of the test bench and IBB 10 brake system for the applied tests is identical to the final mounting position on the railway vehicle, as specified in the standards IEC 60068-2-47: 2005 and IEC 61373: 2010. During vibration and shock tests, the wheel segments correspond to the middle position of the capacity of the slack adjusters, which corresponds to mean wear of wheels and brake shoes.

The figure 6 shows a schematic view of vibration test bench for longitudinal vibrations. The vibration test bench during the tests is mechanically connected to a servo-hydraulic test cylinder. For longitudinal and lateral vibrations, the servo-hydraulic test cylinder is mounted horizontally on massive supporting fixtures, which are fastened to the base of the test bench. On the test bench are fitted four acceleration sensors (Acc 01, Acc 02, Acc 03 and Acc 04), and one sensor for shocks, while on the IBB 10 brake system are assembled two response sensors (Resp 1 and Resp 2), one on the body of the brake cylinder and the other on the hand brake mechanism.

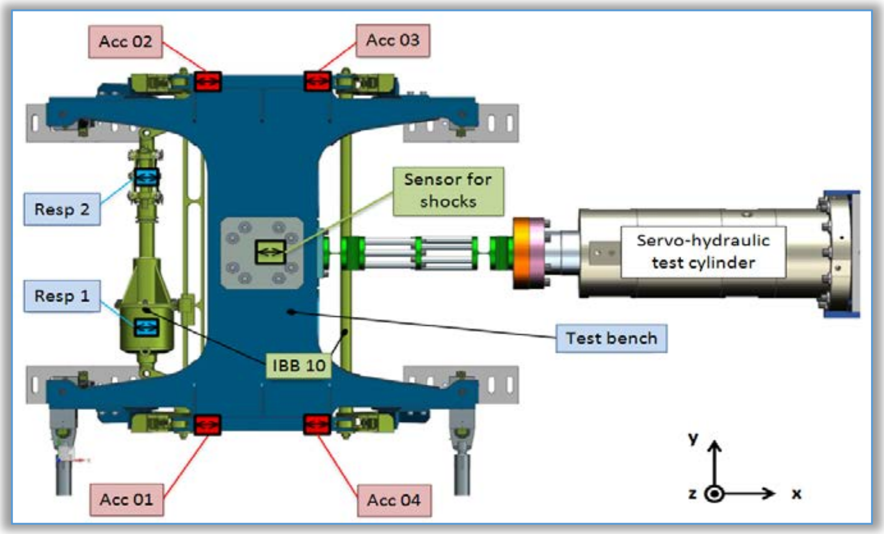

Figure 6. Shematic view of the vibration test bench with IBB 10 for longitudinal tests [7]

The vibration test bench is supported on four flexible support fixtures in vertical direction towards the base plate and two flexible support fixtures in lateral direction. The hydraulic test cylinder is connected via a transmission element with two flexible fixtures at both ends to enable proper force introduction on the test bench. In Figure 7 is shown a schematic diagram of the vibration test bench for lateral vibrations, while Figure 8 shows a schematic diagram of the vertical vibration test bench. As can be seen for vertical vibrations, the test bench must be fully supported by the hydraulic test cylinder.

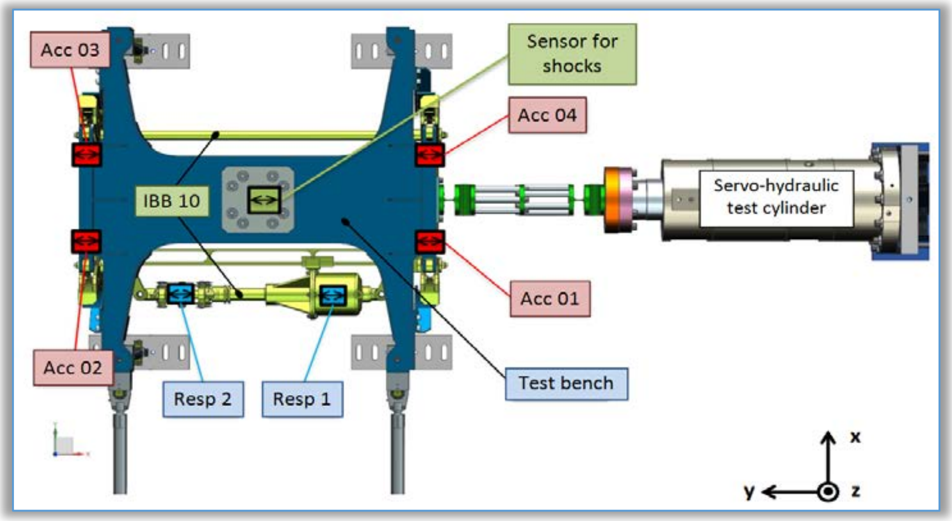

Figure 7. Shematic view of the vibration test bench with IBB 10 for side tests [7]

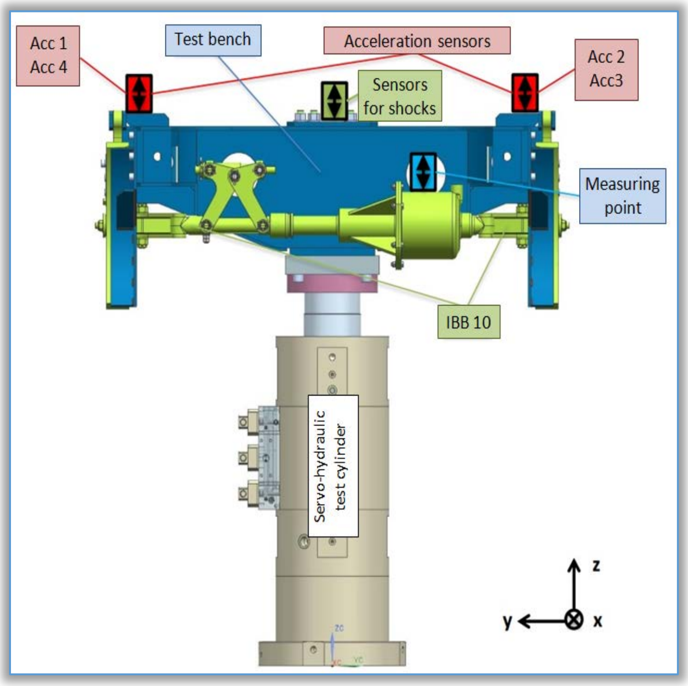

Figure 8. Shematic view of the vibration test bench with IBB 10 for vertical tests [7]

In Figure 9 is shown a photograph of the vibration test bench with IBB 10 brake system for longitudinal vibration and shock tests. In Figure 10 is shown a photograph of the same test bench for side vibration and shock tests.

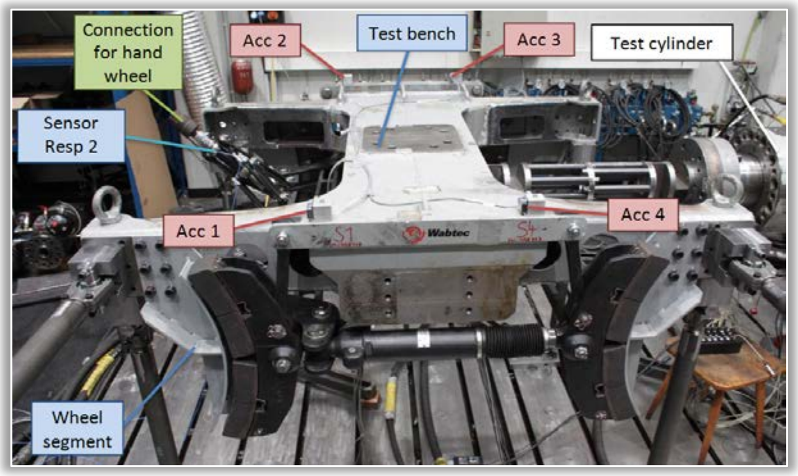

Figure 9. Photograph of vibration test bench and IBB 10 for longitudinal vibration and shock tests [7]

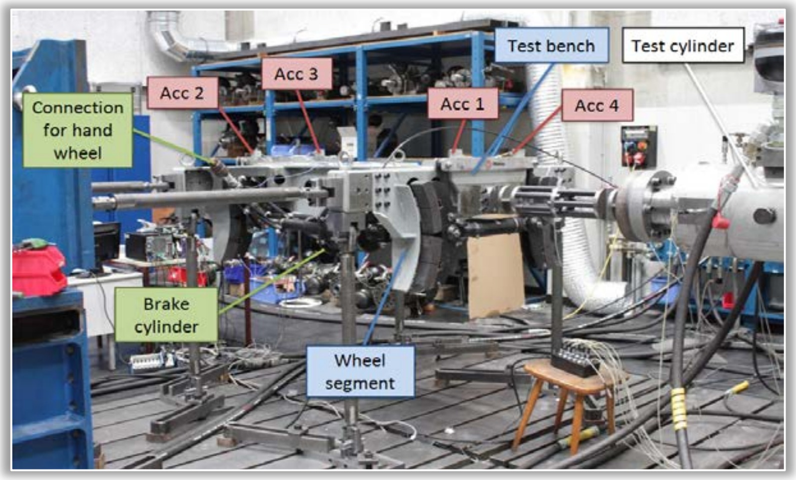

Figure 10. Photograph of vibration test bench and IBB 10 for side vibration and shock tests [7]

One of the most important information that can be obtained during the vibration tests is the FRF. This function serves to identify the resonance frequencies and damping of the tested unit. According to IEC 61373: 2010, taking into account the mass of the innovative brake system IBB 10, it is necessary to determine the FRF between the frequencies f_1=2,2 Hz and f_2=111 Hz. Figure 11 shows FRF diagram from vibration test in vertical direction (z-direction) in the range of 2,2 Hz to 111 Hz. The resonant frequency (the highest peak) is f_{res}=20,25 Hz.

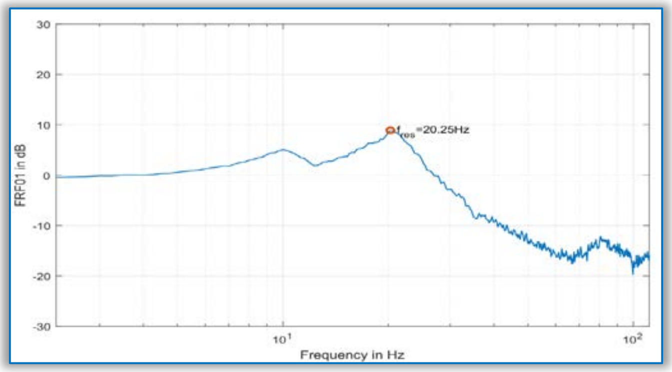

Figure 11. FRF diagram from vibration in vertical direction (z - direction) [7]

Due to irregularities on the rail, shocks appear when the railway vehicle is moving on the rail. Although the shocks can occur in any direction, the most critical are in vertical direction. The shock tests are carried out with a maximum acceleration of a_{max} = 150 m/s^2, with a total of 30 shocks (10 shocks in each direction). Figure 12 shows an acceleration diagram from a vertical shock test. In the diagram is shown change in the acceleration measured by four acceleration sensors (Acc 1, Acc 2, Acc 3 and Acc 4) with a shock test of a_{max} = 150 m/s^2 for a time period of around 0,045 s. The dashed line is the reference line, while the dotted line indicates the limit line. As can be noted, the acceleration of all four sensors is almost equal until achieving the maximum acceleration. After the maximum acceleration the difference between the acceleration in each sensor is increasing as a result of unsymmetrical design of the IBB 10 brake system.

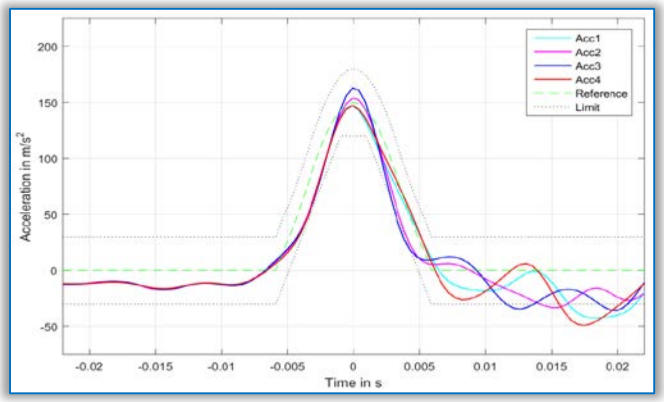

Figure 12. Accelaration diagram of vertical shock test [7]

After the completion of vibration and shock tests, it is necessary to perform functional tests of the brake system to check that it meets the required functionalities. Table 1 shows the results of the functional tests after the vibration and shock tests. As can be noticed, all results are positive.

Table 1. Results of functional tests on IBB 10 after vibration and shock tests [7]

Nr.	Test description	Criteria	Results	
1	Leakage test on 0,7 bar of pressure	<0,01 bar/min	0,003 bar	
2	Leakage test on 3,8 bar of pressure	<0,1 bar/min	0,013 bar	
3	Brake force test on 3,8 bar of pressure	F = 30,0 ± 7% (kN)	F = 31,37 (kN)	
4	Gap test	Total 14^{+4}_{0} (mm) per side	Left side	Right side
			14,6	17,2
5	Minimum position test	605 ± 4,5 (mm)	608	604,5
6	Maximum position test	> 800 (mm)	841	847
7	Hand brake force test	F = min. 26 (kN)	F=36,4 (kN)	

4. CONCLUSIONS

This paper presents a dynamic testing of the innovative braking system IBB 10 for freight wagons. Dynamic testing is one of the most important validation method to be done on a brake systems. Since brake systems are exposed to large static and dynamic loads, carrying out a dynamic test is a complex task which needs to be carried out in a specialized accredited laboratory. Dynamic testing should allow simulating the worst possible cases of field loads. From the results from the dynamic test it can be seen that the innovative IBB 10 system successfully passed all the necessary tests. The results of this test may be useful in the analysis and testing of other types of complex mechanical systems that are exposed to large static and dynamic loads.

Further work can be foreseen in performing other types of tests on the IBB 10 brake system such as: climate chamber test, salt chamber test, field test, etc. Although dynamic testing is one of the most important validation tests, other tests are needed to make full validation of the brake system before it is launched on the market.

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