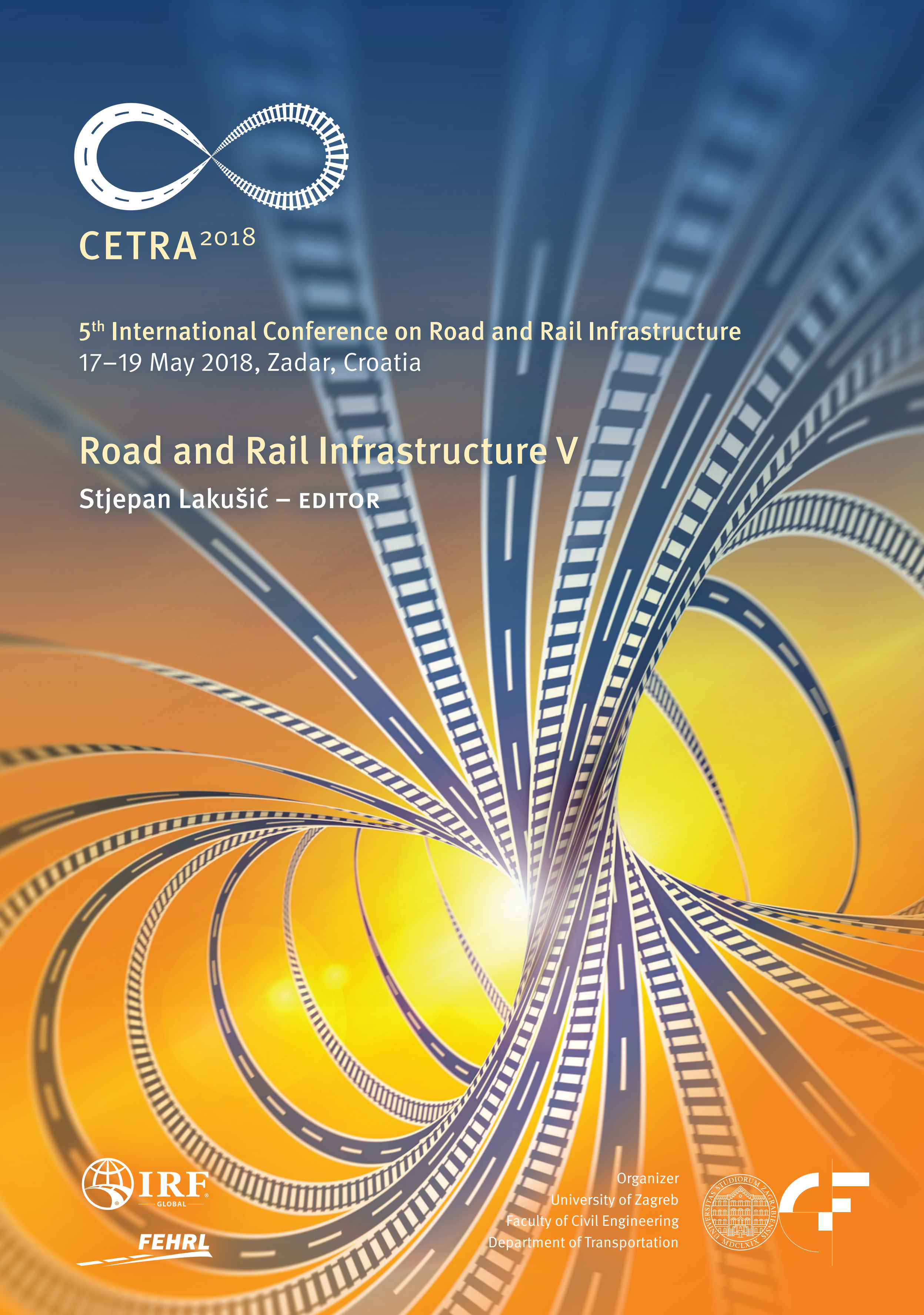

CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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AN INTEGRATED MONITORING SYSTEM FOR CONTINUOUS EVALUATION OF RAILWAY TRACKS FOR EFFICIENT ASSET MANAGEMENT

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Abstract

The maintenance of railway tracks is one of the aspects of the railway infrastructure management activity that most influences the technical and economic performance of this transportation system. It is common practice to support the maintenance actions based on the monitoring of the infrastructure condition, for example by carrying out visual inspections and using dedicated track inspection vehicles. Despite the fact that this traditional approach to evaluate the track, based on its condition, is quite effective, it does not provide useful information on the causes that lead to such reduction in performance. Consequently, the maintenance tends to be more corrective and less preventive. Considering the limitations of the available methods, a R&D project is underway in Portugal aiming at designing, developing and demonstrating the applicability of an innovative and integrated approach to assess the performance of railway tracks, which is also expected to contribute to identifying the causes of some track malfunctions. In this paper we discuss the relevant aspects of this approach and present preliminary results of the tasks currently underway, namely the design and development of the prototype system, including the verification of the measurement chain and its validation in laboratory environment.

Keywords: railway, track stiffness, continuous monitoring, measurement system.

1 Introduction

The geometric quality of a railway track deteriorates throughout its service life, largely due to the successive vehicle passages, which affects the performance of this transportation system. Maintenance and rehabilitation works of railway tracks are costly and have negative impact on its availability. Accurately estimating deterioration rates and anticipating faults can improve the efficiency of asset management activities and minimise the negative impact of those works. To monitor and keep a railway track in adequate conditions it is necessary to collect and analyse a large amount of data, usually regarding the state of the components and the geometric quality of the track, which can be obtained through visual inspections, by using dedicated track inspection vehicles or by other methods [1].

The measurement techniques usually applied make use of sophisticated resources, are adequately accurate, considering this kind of application, and are established as usual procedures by most railway network administrations. However, these entities are frequently faced with a large amount of data which is necessary to transform into valuable information to support decision making regarding maintenance tasks [2]. Concerning the structural analysis of railways tracks, knowing the vertical stiffness of the track and its variation along time and

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space is very important to anticipate critical scenarios of deterioration of the track geometry, which can decrease the performance of the infrastructure [3-5]. Although the traditional procedure to analyse track geometry data established in EN 13848 is effective to detect locations of poor structural performance, usually it does not provide information about the causes that led to that condition.

Previous studies aimed at integrating issues related with the track deterioration and its vertical stiffness in the maintenance management system [2, 3, 6-8]. The experimental approaches ranged from stationary measurement of the vertical deformation of the railway track at discrete points to continuous measurements performed at a given velocity [6]. Some of these studies are still in development and are very expensive, since they require a dedicated vehicle and the track may have to be closed to traffic to carry out the testing [6].

Thus, this project aims at designing, developing and demonstrating the applicability of an innovative and integrated approach to assess the performance of railway tracks, which may also contribute for identifying the causes of track malfunctions. It is meant to consider aspects concerning the dynamic structural response of the train-track interaction, supported on mechanistic concepts, in what regards the analysis of the degradation of the geometric quality.

2 Method

The equipment and software in which the method is supported will be very versatile regarding the operating mode. Specifically, a prototype of an integrated system is being developed to be mounted on board of a self-propelled railway inspection vehicle that allows for: i) the continuous evaluation of the vertical stiffness of the track; ii) the detection of disturbances in the dynamic contact interface between the wheelsets and the rails; and iii) the post-processing of data, considering the structural aspects of the track in order to provide relevant information about malfunctions of the train-track system that affect its behaviour.

To assess the vertical stiffness of the track, the vertical deformation of the two rails is measured, in relation to a reference point fixed to the vehicle's chassis. To accomplish this goal, we measure the deformation of the rail using four displacement transducers located in the zone surrounding each wheel (loaded condition) and two other, located at mid-span of the vehicle (unloaded condition). Having determined the track deformation, due to the loading, and since the load is known, one may determine the vertical stiffness of the track. Although, this method poses some challenges, namely: i) the two sets of displacement measurements, regarding the loaded and unloaded conditions, performed at different moments, have to be synchronised; and ii) displacement data needs to be compensated due to the relative motion between chassis and axles allowed by vehicle suspension. To accomplish the first task, we use the velocity of the vehicle; for the second task, we use two triaxial accelerometers to determine the position of the vehicle's body with respect to its wheel-sets.

3 Measurement system setup

The goal is to develop a versatile measurement system, to be mounted on board of a self-propelled railway inspection vehicle. In this case, the vehicle is a DD 450B model, manufactured by SVI. This vehicle is 13.27 m long, 3.30 m wide and 3.00 m high. It can travel at speeds up to 90 km/h and weights 24 t. It has four tanks with capacity up to 11,600 litres, which will be useful to tests different axle loads in future field tests. The measurement system basically comprises four components (Figure 1): i) sensors; ii) data acquisition system; iii) industrial computer; and iv) custom software application.

The set of sensors comprises six non-contact laser-based uniaxial displacement transducers and six 3D accelerometers (two high-sensitive and four high-range).

To measure the vertical stiffness of the track, six non-contact displacement transducers are used, with a configurable measurement range up to 600 mm (200 to 800 mm). Four of them are in the chassis, over each wheel and pointing at the axles, and the other two are at the middle of the chassis, pointing at the railheads. The transducers over the wheels measure the distance between the chassis and the respective wheel, which differs from the true distance to the rail by a constant value, proportional to wheel and axle radius. The transducers located at mid-span of the chassis are used to measure the unloaded condition of the track.

Two high-sensitive 3D accelerometers are used to measure the relative motion between chassis and wheelsets. The generalised coordinates will be obtained by acceleration integration. It will be used to compensate the displacement measured by each of the six displacement transducers. These accelerometers, mounted symmetrically inside of each cabin, in the back and in the front of the vehicle, are scale configurable and they measure up to ±39.2 m/s^2 (±4 g). Four accelerometers, capable of measuring up to ±4,900 m/s^2 (±500 g), are used to assess the dynamic of the contact interface between the wheelsets and the rails.

The data acquisition system comprises: i) a data collector and a supervisor unit system – Q.station 101; ii) four measuring modules, with 4 inputs each, for IEPE sensors – Q.bloxx A111 – to measure the analog signal provided by the wheels triaxial accelerometers; and iii) four measuring modules, with 4 galvanic isolated inputs each – Q.bloxx A123 – to measure the analog signal provided by the displacement transducers and compartment accelerometers. Considering that the Q.Station has four RS-488 ports for connecting to the eight Q.bloxx modules, to maximise the data bandwidth, we have connected two modules per port. The sampling frequency is configured at 1,000 samples per second for all variables with the data being transferred to the computer by a FTP connection. If the vehicle's velocity is 20 m/s, this means a spatial resolution of roughly 20 mm.

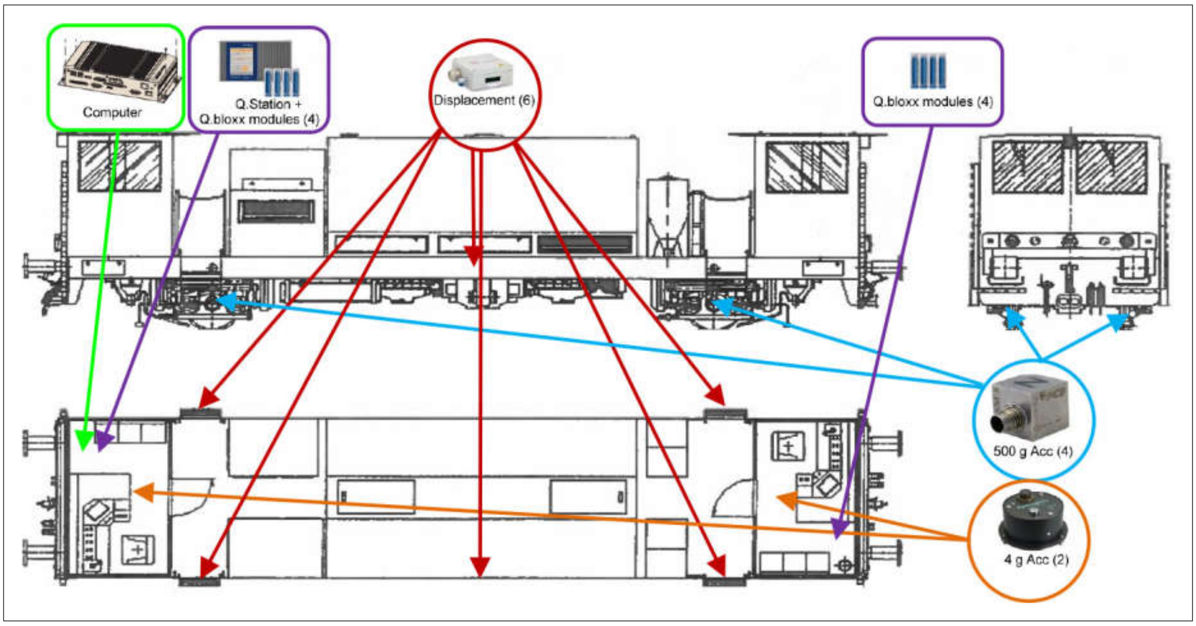

Figure 1 Schematic layout of the inspection vehicle and measurement system

For the first stage data processing we have chosen a high-performance industrial computer. A software application is being developed in LabVIEW to process the data sent by the data acquisition system, showing the main results in graphs and numerical values. The original and processed data is stored in a SSD memory disk for final assessment and archive. The software application is being developed to provide a structural analysis of the railway track, based on the measured data. In the end, it is expected to reach a high reduction of the amount of acquired data.

Considering the spatial distribution of the sensors in the vehicle, it was decided to implement a distributed architecture for the measurement system, with the data acquisition system distributed between two cabinets: one located in the front of the vehicle and the other in the rear (Figure 2). Four data acquisition modules are mounted in each cabinet for the acquisition of the signals provided by the sensors. The front cabinet contains also the Q.Station, which collects the data from the acquisition modules, the computer and the power supply for the complete system (Figure 2a). A cable connecting the two cabinets provides the communication support between the Q.Station and the remote acquisition modules, as well as the power supply to the system mounted in the rear.

4 Experimental tests

So far, the assessment of the measurement test comprised two tests: a verification of the chain measurement, applied to each sensor and the respective acquisition channel, and a more general test, involving half of the sensors, carried out in a cyclic load test of a section of a railway track physical model at LNEC.

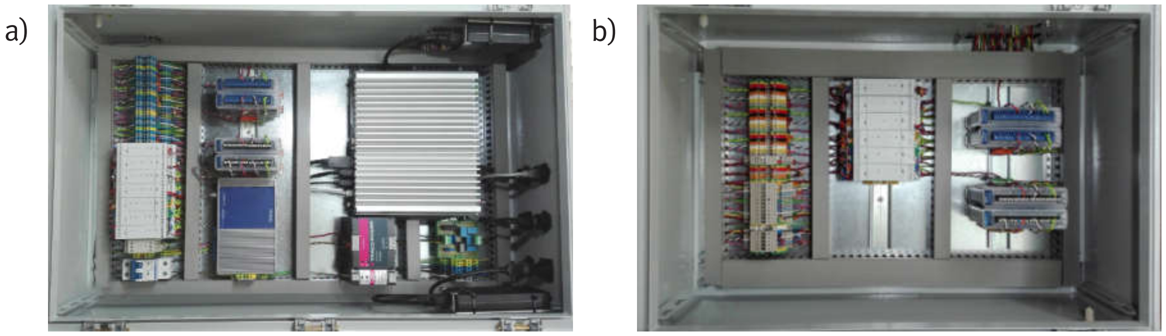

Figure 2 Data acquisition system cabinets: a) leading; b) trailing

4.1 Measurement verification

Although the manufacturer has provided the data regarding the sensitivity for all sensors, the authors decided to perform a first test to assess the reliability of the complete measurement chain, which includes the sensor, the signal conditioner and the acquisition system.
Assessing an accelerometer up to ±500 g requires dedicated equipment and access to a high accuracy reference accelerometer. Lacking that type of resources it is common practice to carry out a simpler test to assess the sensitivity at low acceleration. We have used a ±5 g accelerometer as reference and a unidirectional compact shaking table to impose acceleration in the direction of each axis in turn and assess accelerometer cross axes interaction (Figure 3a).

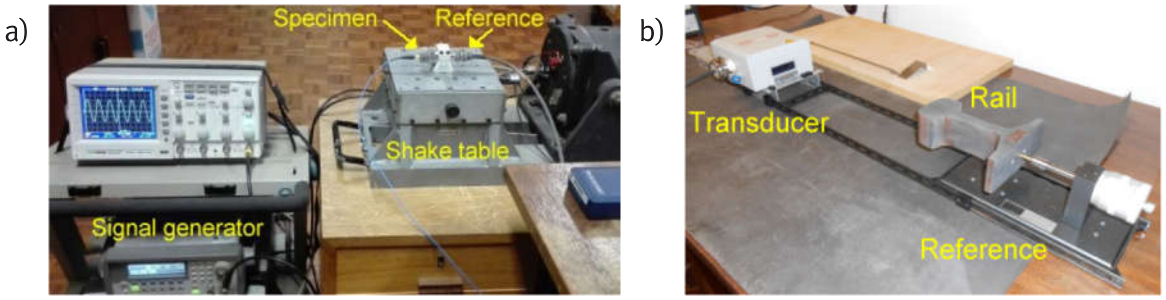

Figure 3 Verification test setup for: a) accelerations and b) displacements

In Figure 4 we present some results obtained with the accelerometer (top) and with the reference (bottom): i) sinusoidal signals with ≈2.8 mm peak-to-peak amplitude at 10 Hz (left) and with ≈5 µm at 200 Hz (center-left); ii) a square signal with ≈1.8 mm at 30 Hz (center-right); iii) a mass impact test performed with two identical accelerometers. Despite the low accelerations applied to the accelerometers (less than 1 g), it was possible to identify the fundamental frequency, even at low frequency, and the amplitude was also very close to the reference value. Further, the two units also follow a similar shape, although with a slight different amplitude, perhaps due to the location of the mass impact. The results have also shown that the induced acceleration in the perpendicular axes is small and, certainly, part of this value is due to a misalignment in the setup.

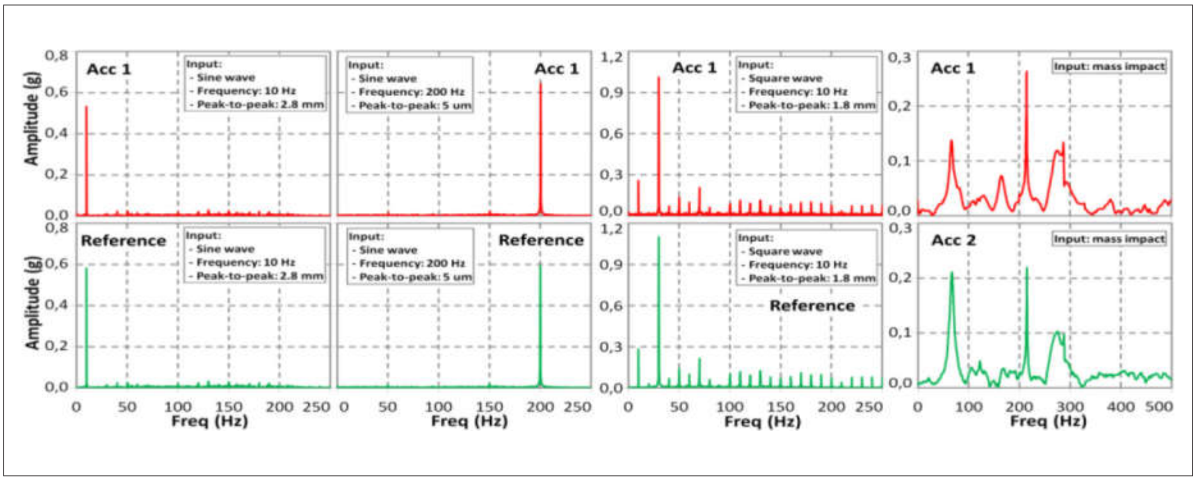

Figure 4 Comparison results between a test accelerometer and reference (left and center), and between two identical units with a mass impact (right)

To verify the displacement transducers we used a calibrated Mitutoyo micrometer and a 3D printed replica of a UIC54 rail (Figure 3b). Despite of this type of transducer has a nominal range of 600 mm, for the application, the expected measurement range is just a small fraction of that value. Thus, each transducer was subject to several tests in two different zones of its nominal range. Figure 5 depicts some results for one of the transducers. The curves represent the deviation regarding the reference, for three different trials. It is visible that the deviation changes with the distance to the target, though it is always lower than ±0.7 mm. However, considering the shape of the deviation curves and since the measurement range in the application is less than 50 mm, there is room for improvement.

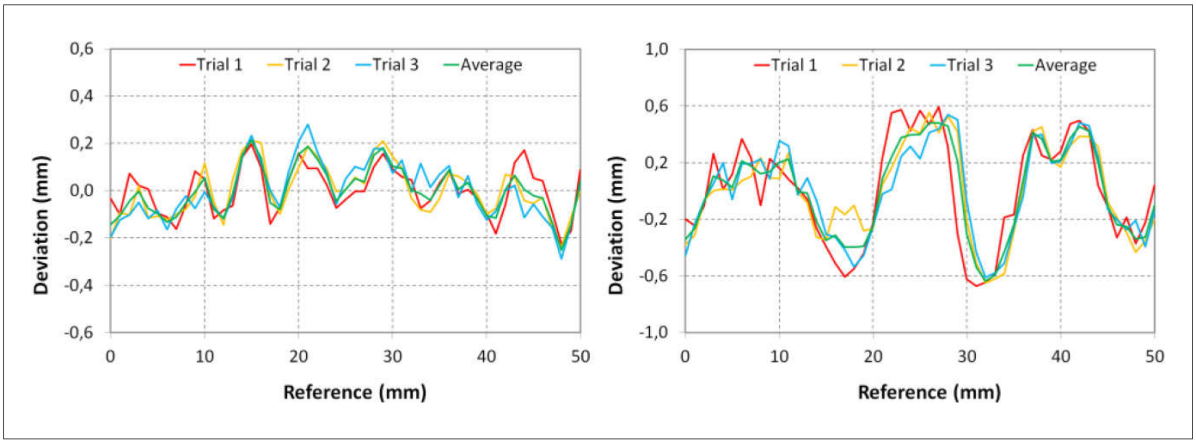

Figure 5 Deviation results obtained with the transducer in the ranges 175 to 240 mm (left) and 375 to 440 mm (right)

4.2 Cyclic load test of a section of a railway track

The second assessment test was carried out in a true scale railway track physical model, using a hydraulic system to apply cyclic loads to a section of the model, as shown in Figure 6. In this case, since the space to mount all sensors was tight, it was decided to use only half of the sensors. The railway model was submitted to a set of load cycles at 1 Hz and with a peak load of about 50 kN. Some of the results are presented in Figure 7.

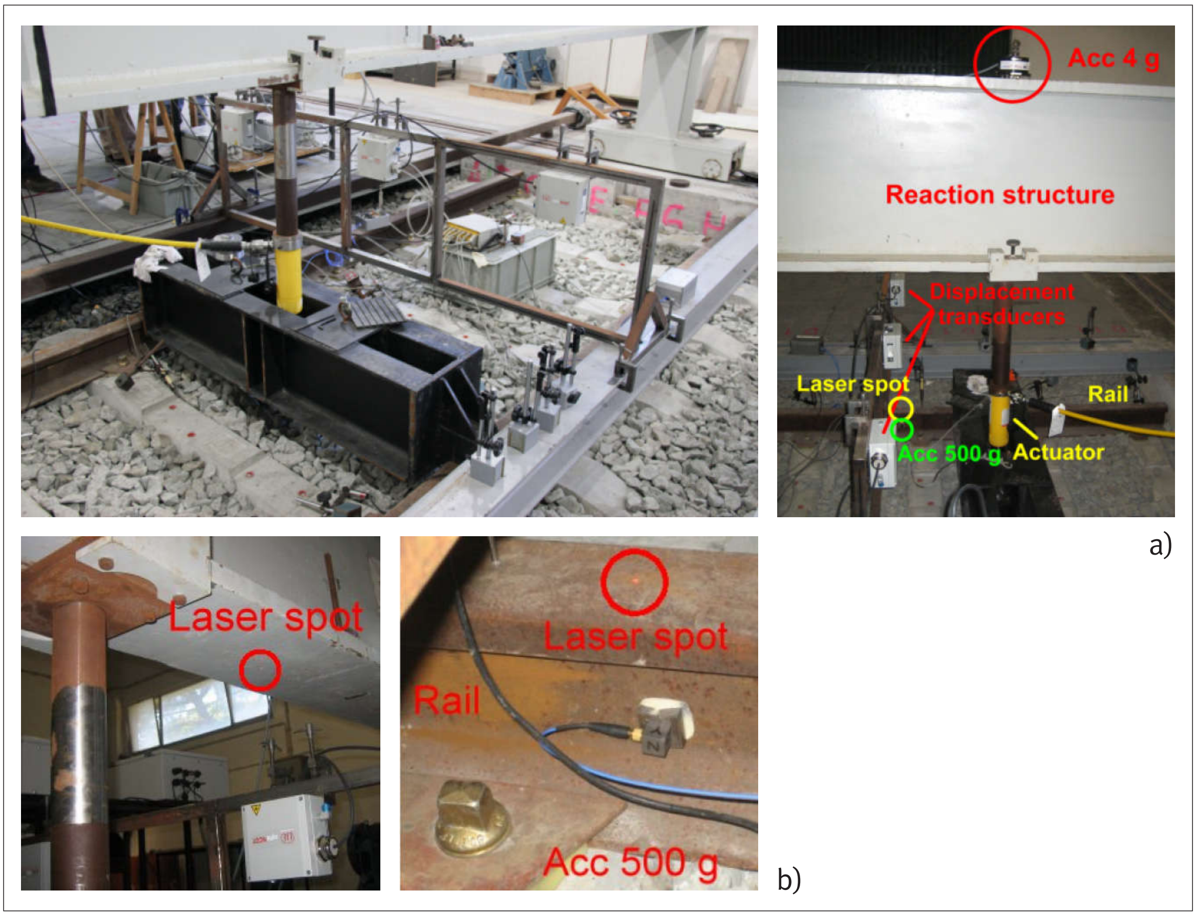

Figure 6 Cyclic load test: a) Cyclic loading apparatus, b) details of the instrumentation

The data obtained from the accelerometers show that the load's release is more severe for the structure than the loading due to a slower load application. Regarding the displacement data, it is worth mentioning the ringing of the rail and of the reaction structure, which is in agreement with the acceleration data. Moreover, the displacement results agree with those measured by high sensitivity LVDT transducers used to monitor the behaviour of the physical model.

5 Final remarks and future work

A measurement system setup was presented for assessment of the stiffness of a railway track as well as the detection of disturbances in the dynamic contact interface between the wheelsets and the rails. The results obtained so far suggest that it will be possible to accomplish these goals. At this moment we are starting to mount the measurement system in the vehicle, in order to carry out quasi-static and dynamic tests on an instrumented railway track for validation purposes.

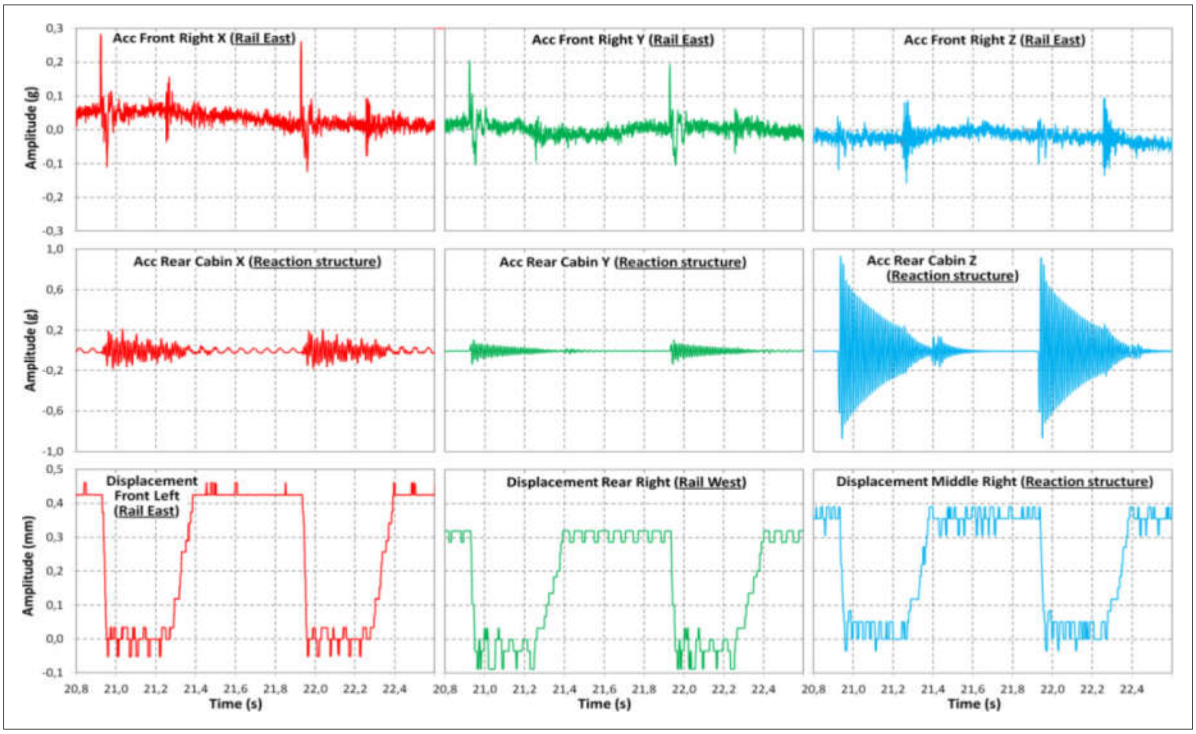

Figure 7 Data from a 500 g accelerometer mounted in the rail (top); from a 4 g accelerometer mounted in the reaction structure (center); and from the three displacement transducers (bottom)

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