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Design of an Innovative Test Bench to Calibrate Instrumented Wheelsets

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Abstract

This paper deals with the design of a new static rig developed by the University of Florence and Italcertifer S.p.A. The system can provide experimental calibration of different kinds of wheelsets according to the standard specifications and more severe conditions. It is the first bench where the wheelset is supported in a statically determinate way and it can rotate around its axis, allowing the optimal calibration of the measuring strain-gauge bridges.

Keywords: measuring wheelset, calibration, test rig, force reconstruction, ill-conditioning.

1 Introduction

Running dynamics is fundamental to determine the safety of a railway vehicle, i.e. the margin that exists with respect to derailments and the deterioration of track geometry quality considering the mutually exchanged forces between the wheels and the rails.

Regulations require an online measurement of the behaviour of the railway vehicle, including the simultaneous measurement of the vertical (Q) and lateral (Y) forces, exchanged at the wheel-rail interface [1]. Typically, measuring wheelsets are instrumented with strain gauges and telemetry systems providing power supply and sending signals via radio.

In order to use an instrumented wheelset as a measuring device, a preliminary calibration is required. During this phase known forces are applied to the wheelset and the output signals of strain gauge bridges, glued on the wheels and on the axle, are acquired [2]. It is then possible to identify the matrix relationship between the vector of applied forces and the vector of strain gauge measurements, with the aim to estimate contact forces [3].

One the biggest problems intrinsic in this procedure is the influence of lateral loads on signals form strain gauge bridges designed to detect vertical forces and vice versa: the calibration matrix is not diagonal and the inversion process required to estimate the input forces from the strains can be ill-conditioned, making the estimation of contact forces prone to errors.

In order to limit this issue a new calibration bench is designed, based on an innovative layout that does not overconstrain the wheelset under calibration. Any desired combination of vertical, lateral and longitudinal forces can be applied simultaneously. Another distinct feature of the calibration bench is the possibility to continuously change the contact point while the wheelset is slowly rotated over special rollers.

The paper describes the philosophy of the bench and the solutions designed to reach the aforementioned targets.

2 Test rig requirements and design

The basic requirements of the test rig were defined as the envelope of the geometrical parameters of the majority of existing wheelsets. The main geometric parameters taken into account were:

- rail gauge;
- wheel diameter;
- rail profile.

Beyond the standard gauge of 1435 mm there are many example of narrow gauge railways and values up to 1668 mm can be found in Spain and Portugal, while wheels diameter depends on many parameters.

The test bench is designed to calibrate instrumented wheelset under the action of known forces. To be able to calibrate almost any kind of instrumented wheelset, any combination of independent lateral, vertical and longitudinal force can be applied. To such goal, the test rig is equipped with five hydraulic actuators able to apply quasi-static loads. Due to safety reasons for operators, maximum working pressure is limited to 300 bar.

The control of the actuators is performed by a closed loop with a force retroaction, using load cells. The actuators are monitored and controlled by a PLC, configurable by the test operator. It controls the position and the force exerted by all of actuators and if a limit value is exceeded, the system comes to a safe emergency stop.

The test rig is designed in order to accommodate calibration wheelsets with the dimensions summarized in Table 1, where also the main force actuator properties are shown.

Design parameter	Range	Stroke [mm]	Bore [mm]	Force transducer
rail gauge	750÷1686 mm			
wheel diameter	610÷1250 mm			
rail profile	arbitrary			
radial force $F_{z,max}$, Q, V	170 kN	45	171.6	Pin load cell Force washers
axial force $F_{y,max}$, Y, L	135 kN	50	100	Pin load cell
tangential force, $F_{x,max}$, X	40 kN	50	80	Pin load cell

Table 1: Design parameters for the calibration test bench. Any combination of the parameters is acceptable.

A general view of the test rig is shown in Figure 1. It is modular and it was designed to be easily transportable, thanks to its dimensions (5x2x2 m) and the reduced overall mass (approximately three tons).

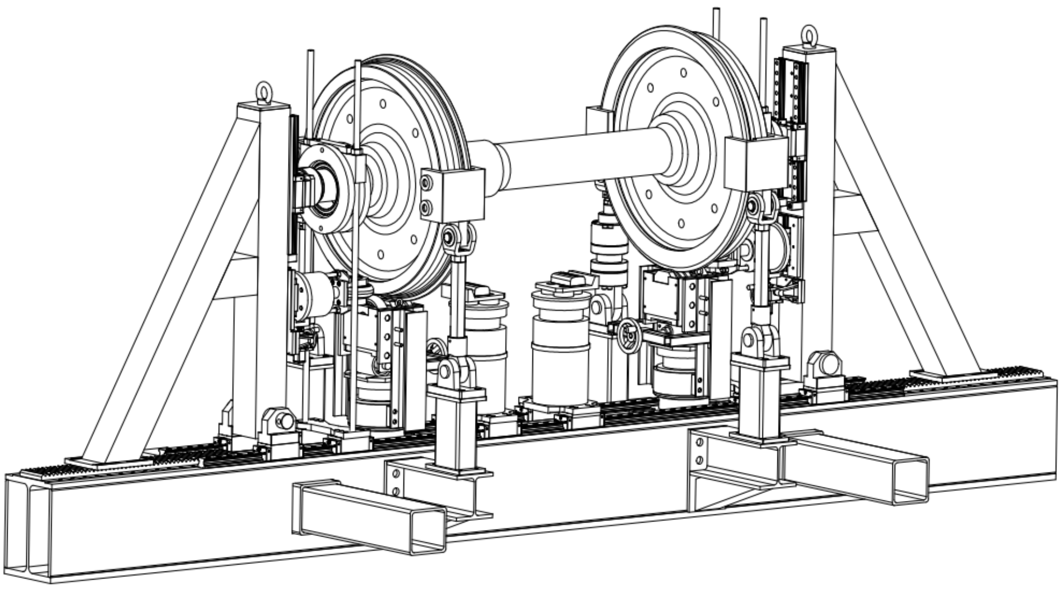

Figure 1: Calibration test bench general view.

Figure 2 shows the forces that can be applied to the wheelset under calibration. In Europe, radial (vertical) forces are indicated with Q, axial (lateral) forces with Y and tangential (longitudinal) forces with X. For design reasons the test bench cannot withstand longitudinal loads X that are horizontal. As explained in the paper, tangential forces are given by a set of balanced vertical forces that impose a torsion to the axle.

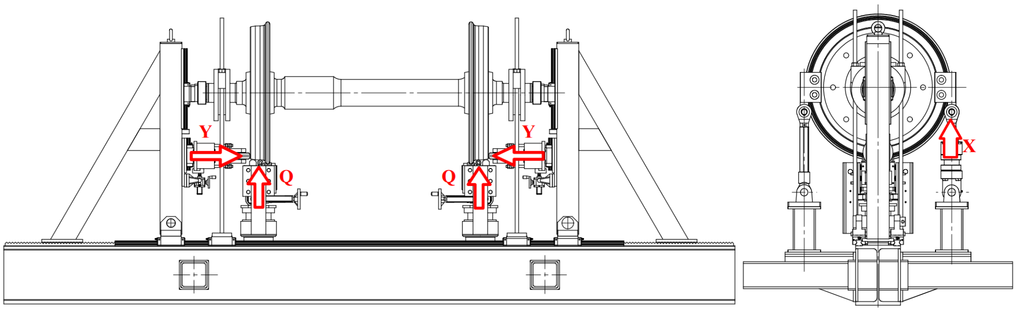

Figure 2: Forces applicable to the wheelset under calibration mounted on the test bench. *Q*-forces will be named “radial”, *Y*-forces will be named “axial” and *X*-forces will be named “tangential”.

3 Test rig requirements and design

The test rig is composed by seven sub-systems, that are described in the following:
1. welded steel main frame;
2. radial force unit: roller version;
3. axial force unit;
4. radial force unit: rail version;
5. tangential force unit and constraints
6. radial constraint;
7. axial constraint;
8. supporting columns.

3.1 Welded steel main frame

The main element of the frame is an H-beam five metres long stiffened by use two sheets welded on each side (Figure 3). Vertical loads are either on the vertical plane or on sides due to presence of the roller guides that will be described later, and this solution ensures the maximum stiffness. The upper surface of the beam has a matrix of threaded holes arranged in order to fix several devices and the other sub-systems in different positions.

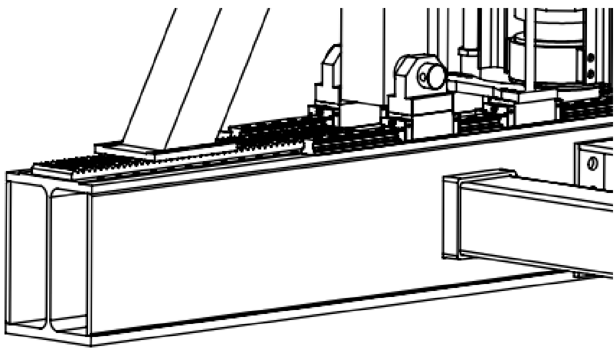

Figure 3: Close-up on the welded main frame steel composite beam

3.2 Radial force unit: roller version

This unit, shown in Figure 4, is one of the innovative solutions introduced in the project of the test rig. Its key features are:

- statically determined constraint of the wheelset;
- improvement of the S/N ratio of the strain measurement;
- continuous variation of the contact point position;
- the wheelset does not need to be lifted and can be rotated (manually or automatically) during the calibration, giving the possibility to overcome the main disadvantage of the existing static benches.

A large diameter / short stroke hydraulic cylinder is placed under this roller actuates the upper unit equipped with rollers and load cells (Figure 4). With this arrangement the radial force always passes through the cylinder, thereby limiting cylinder bending. The choice to limit the stroke is mainly due to keep the height of the test rig as small as possible for safety reasons.

The wheelset rests on two pairs of rollers. Each wheel is laterally constrained on the flange by a groove made in one of the rollers, while the other roller has a toroidal surface and acts like a support. The rollers can be vertically adjusted by using suitable shims to match virtually any wheel profile (either new or worn). As a result the radial force is transmitted according to the sketch shown in Figure 4.

The main advantages of this solution can be summarized as follows:

- the lower wheel, mounted just above the vertical hydraulic actuator, can be shifted (when unloaded) to arbitrarily change the "equivalent" contact point. The stress distribution in the wheel rim is obviously different, but the stress distribution in the wheel web, where strain gauges are normally installed, in insensitive to this local condition;
- with this solution it is possible to apply vertical forces also in the flange area (see for example the rightmost drawing in Figure 4), a condition normally impossible with other test benches;
- the wheel can be rotated during the calibration, even if at low speed, to check for example the telemetry equipment;
- although the estimation of actual contact forces is limited by the practical impossibility to place any sensor in the contact area, the problem is minimized by the use of load cell pins mounted in the rollers, i.e. the closest point to the wheel-roller contacts where the forces are exchanged. This improves the quality of the measurement, especially the S/N ratio;
- any lateral force is filtered by the rotation of the lower wheel. When loaded either radially or axially, the contact point can freely move. This is possibly the most important feature of the test bench compared to existing benches.

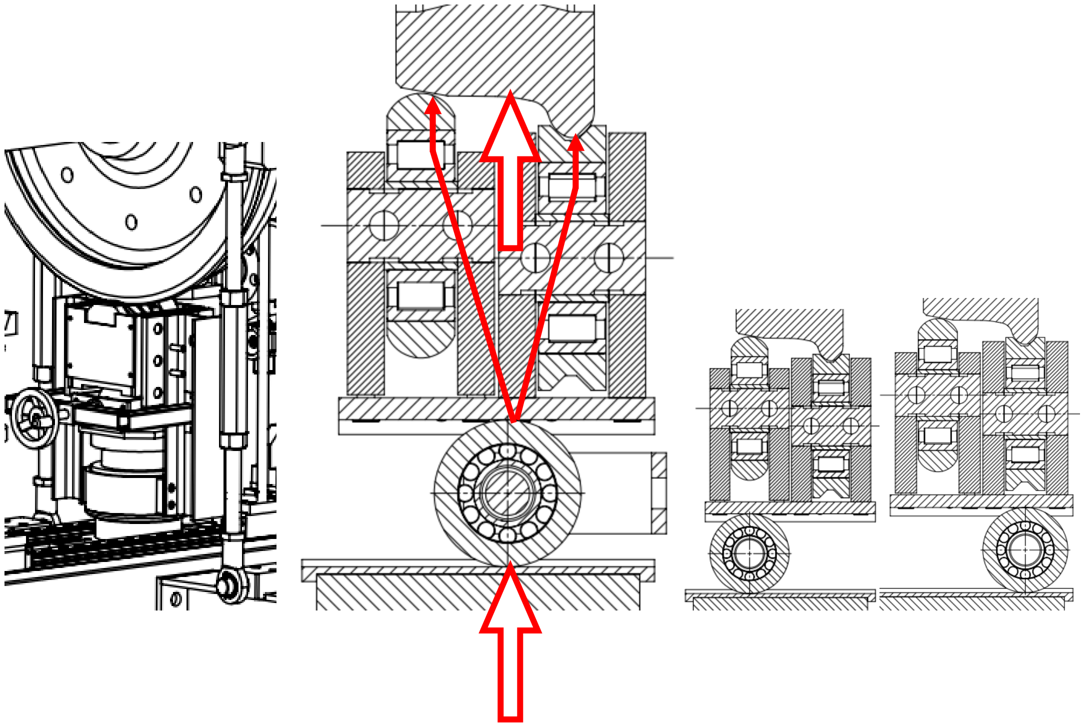

Figure 4: Radial load unit with rollers. General view (left), cross-section with load path and equivalent contact point (mid) and extreme positions of the units on both wheels (right). Under the action of lateral actions the lower wheel can rotate freely avoiding any lateral reaction forces (it is free in this direction).

The assembly of the two rollers with their supports is contained in a box that has two degrees of freedom:

- the translation along the vertical direction that is allowed by two parallel vertical surface equipped with ball transfer units;
- the rotation around the perpendicular direction respect to wheelset axis: this d.o.f. is allowed by the contact between the base plate (on which the supports are mounted) and the lower roller, always in cooperation with ball transfer units

Thanks to these constraint conditions the wheelset is statically determined: as aforementioned, the main consequence is the absence of force components in directions different from the loading one. Strain measurements are therefore not affected by cross-talk.

3.3 Axial force unit

The subsystem dedicated to the application of axial force to the wheel is shown in Figure 5. The goal was in this case to design an axial loading system that is intrinsically insensitive to radial loads to ensure the static determination of the wheelset and the independence of measured strains on the wheel.

The subsystem consists of a roller mounted on a special support, a hydraulic cylinder, a screw jack and a linear guide. The support of this roller is similar to the one used in the vertical force unit. With the use of pin load cell it is possible to place the force transducer close to the load application point.

With this system it is possible to rotate the wheelset without the necessity to lift it when the load application point is changed. The load application point can be continuously changed by the combined use of a linear guide behind the cylinder and a screw jack under the cylinder actuated by the operator.

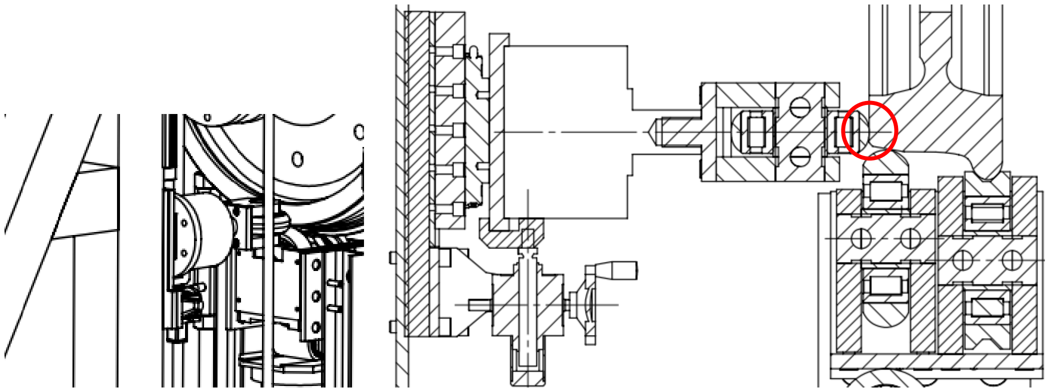

Figure 5: Axial force unit. The load application point is highlighted with a red circle.

3.4 Radial and axial force unit: rail version

A different system to apply radial and axial loads is shown in Figure 6. It is made of an arbitrary railhead slice whose inclination can be adjusted with shims (e.g. 1:20 or 1:40), an upper drilled plate, three pins, three load cell, a lower drilled plate, a hydraulic cylinder and two linear guides.

This unit replicates the wheel-rail contact but has the disadvantage of the impossibility to rotate the wheelset during the calibration phase. It is intended mainly to observe the behaviour under lateral loads and the actual contact conditions of a standing wheel.

In order to measure the radial load applied by the cylinder, the forces measured by three load cells placed under the upper plate accommodating the rail head are summed up, while the line of action is determined by proper ratios between these quantities.

With this unit is possible to apply load distributions similar to those encountered in service, in terms of simultaneous presence of radial and axial forces and friction conditions. This feature allows the validation of the calibration of the measuring chain.

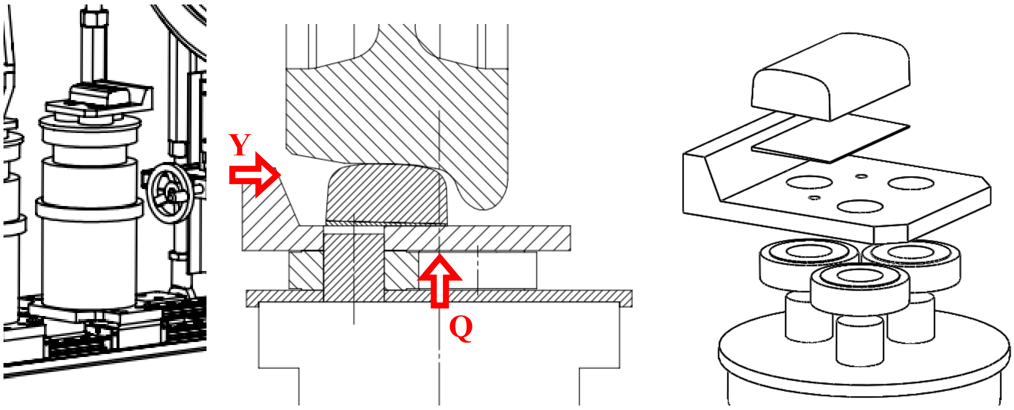

Figure 6: Vertical force unit: rail version. Left: close-up. Mid: cross-section with a load cell. Right: exploded view of the subassembly.

The assembly can rotate around the vertical axis of the cylinder, in this way it is possible to evaluate the influence of the angle of attack and even double contact point (a typical double contact point scenario when the rail vehicle is negotiating a tight curve).

It is possible to constrain the wheelset in a statically determinate configuration also with this unit, thanks to the linear roller guides installed under the hydraulic cylinder.

3.5 Tangential force unit and constraints

The layout of the test rig is characterized by the co planarity of vertical and lateral loads, that lie on a vertical plane. As a result, the test bench is not design to support any load acting along the transverse axis of the bench. In order to maintain this co planarity and to apply at the same time, the only possibility to apply a tangential load to the wheelset can be achieved with a torque. This is seen by the wheelset as a longitudinal equivalent force *X*.

The torque is applied through a system made of a vertical actuator, that provides the requested load, and four custom-made clamps. Each wheel is locked with two clamps at 180° (see Figure 7), but only one of them is linked with the actuator. The other three clamps are fixed and provide only the constraint between the wheelset and the test rig.

It is evident that elasticity of the entire system will be such that the entire wheelset will move under the load, but the statically determinate condition still holds and this load has no influence on the other loads (either radial or axial) possibly applied to the wheelset.

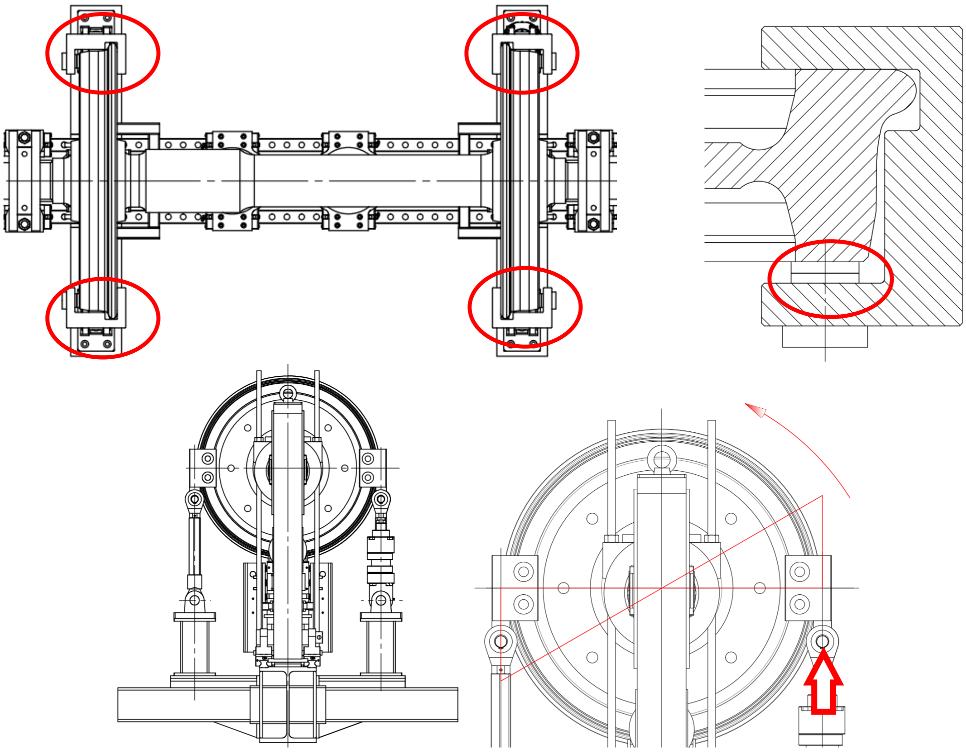

Figure 7: Top left: arrangement of the clamps. Top right: section of the clamp. Two screws that provide the locking of the wheel are highlighted. Bottom left: side view of test rig. Bottom right: load distribution of the longitudinal load.

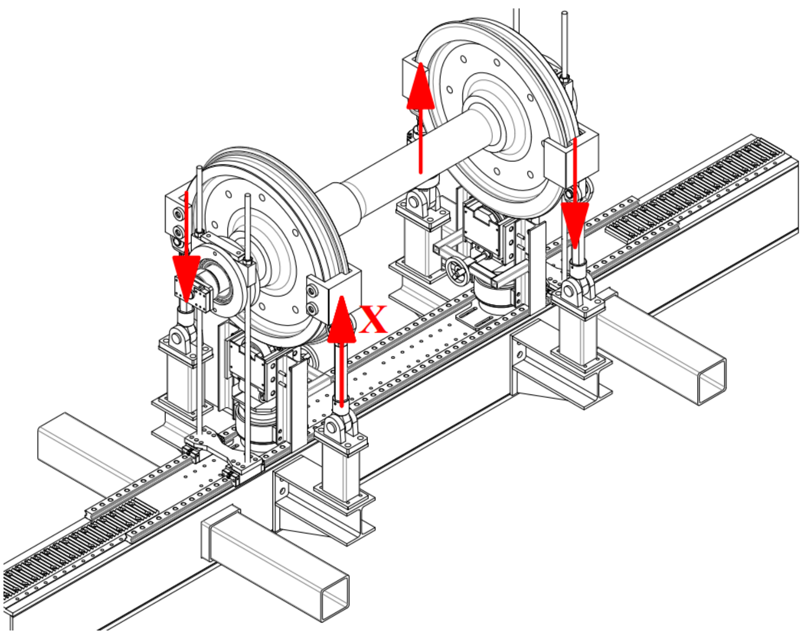

Figure 8: Load distribution of tangential force unit

3.6 Radial constraint

This subsystem reacts the radial forces applied by either the radial systems described above by using a collar and threaded bars. The collar is mounted on the axle journal and its main element is a spherical roller bearing, while the threaded bars link the collar to linear guides (Figure 9). With this arrangement the bars are never subjected to bending but only to normal force (traction); the presence of linear roller guides automatically centres the unit in the desired position.

The use of a self-aligning bearing is justified by the following advantages:

- it is insensitive to any axle misalignment or elastic deformation, always resulting in a statically determined restrained wheelset;
- it has an overabundant static load rating (C_0=1200 kN), much larger than the maximum vertical load;
- although its internal diameter is larger than the axle journal diameter, local stresses according to Hertz theory are reasonably low due to the opposite curvature of contact surfaces (one concave and one convex);
- its internal diameter (160 mm) fits the majority of axle journals (and can be changed if needed).

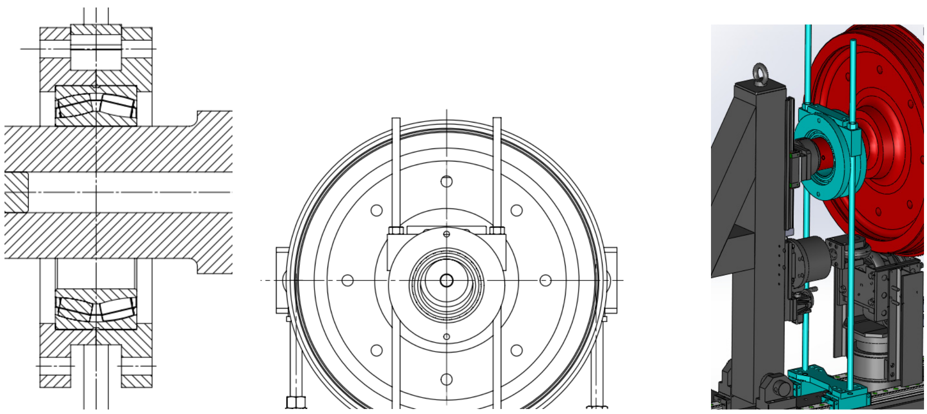

Figure 9: Vertical restraint. Left: section of the collar including a self-aligning spherical bearing. Mid: arrangement of the vertical constraint. Right: axonometric view of the sub-system (in cyan).

3.7 Axial constraint

The axial constraint reacts any lateral loads possibly applied to the wheelset under calibration. The core of the unit is a spherical roller thrust bearing that acts like a spherical hinge allowing the free deformation of the axle. The operating principle is shown in Figure 10 where the lateral load passes through the chain formed by the interface between the axle and the bearing, the bearing, two plates and the linear guides.

The design of the two plates is made in order to improve the assembly of the components in the set-up phase and make the test rig suitable for every axle. Also this system has an overabundant static load capacity allowing a free rotation of the wheelset. The presence of the linear roller guide avoids the appearance of any undesired axial force, keeping the statically determinate restraint condition of the wheelset.

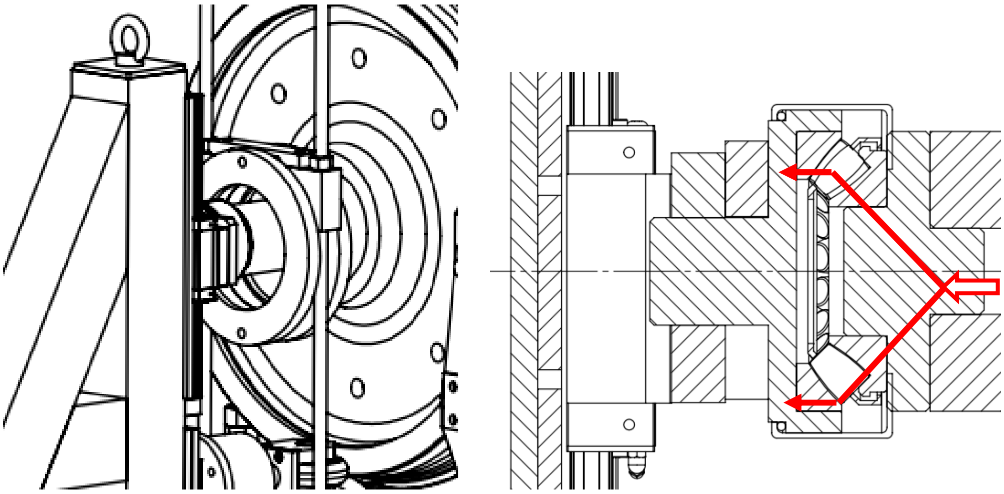

Figure 10: Lateral constraint. Left: close-up in the assembly. Right: cross section with axial force path.

3.8 Supporting columns

This simple subsystem is made of stiff welded square hollow beams to reduce the deformations under the load application. The columns are locked to the main H-beam but can be moved along its axis during the set-up phase. As the position can be set only in some predetermined positions by the use of a prismatic fit, based on plates with multiple teeth, the vertical beam is supported by linear guides. This mounting is very stiff but it is statically undetermined, so it will require some care during mounting.

The use of a toothed connection provides positive locking transmission of most of any high lateral avoiding any possible sliding during the whole calibration phase.

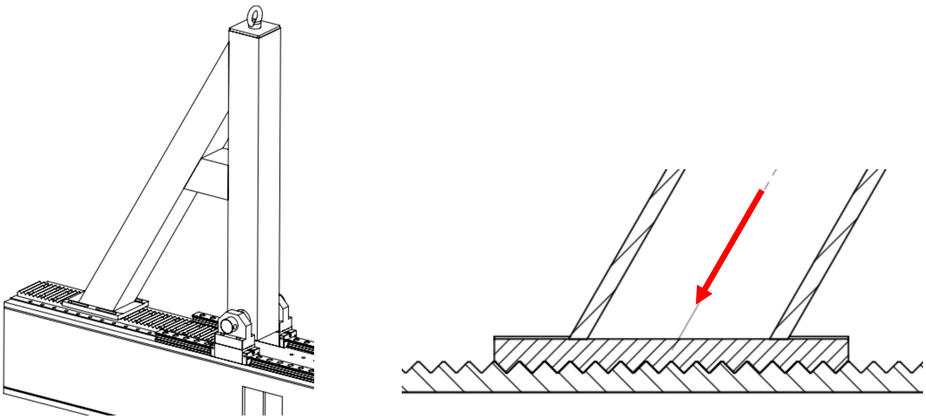

Figure 11: Left: axonometric view of the column. Right: detail of the toothed positive fit.

4 Conclusions

In this paper the design of a new test rig for the calibration of instrumented wheelsets, developed by the University of Florence and Italcertifer S.p.A. has been presented. As shown, the system overcomes many drawbacks of the existing static benches, for example allowing the rotation of the wheelset during the calibration, the constraint conditions that avoid cross-talk between the channels and the continuous variation of the contact point position.

The test rig is suitable to perform several tests in order to give the possibility to extend the range of the research in this important field of the wheel-rail contact problem.

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