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Design of a test rig for railway Axle-boxes

N. Bosso[a,]*, A. Gugliotta[a], N. Zampieri[a]

[a]Politecnico di Torino, C.so duca degli Abruzzi 24, 10129 Torino, Italy

Abstract

Railway axle-boxes are one of the more critical components of the railway vehicle. The axle-box is the housing of the bearings, which support the axle-load of the vehicle, and the confinement of the lubricant required to maintain the performances of the bearings. Therefore, the axle-box is involved both in problems related to vehicle safety, and in problems related to maintenance, becoming an important part of the life cycle cost of the vehicle. To improve safety and reliability of the axle-box, in recent years, diagnostic systems are adopted to detect malfunctions, damage or degradation of the performances of the bearings. This is made both using onboard or wayside monitoring systems, which can be based on vibration or thermal analysis. The effectiveness of these systems rely in the accuracy of the algorithms, that are used to predict the condition status of the bearings. Therefore, it is necessary to be able to validate and tune the algorithms, by means of experimental tests. The tests can be performed on the track, but this implies high variability, costs and the impossibility to experience critical conditions (due to the related risks).
The aim of this work is to design an experimental test rig, able to perform tests on railway axle-boxes and to reproduce the real conditions (axle-load, velocity). Several design layout are considered, each one evidencing some benefits and some limitations. The use of the test rig allows to reproduce different failures of the bearings in a safe environment. The repeatability of the tests and the controlled environmental conditions, allow a better setup of the monitoring system being developed.

Keywords: Railway Axle-box, bearing test rig, railway monitoring.

1. Introduction

One of the most critical mechanical components of the railway vehicle is the axle-box. In fact, this component contains the bearings that must support the axle-load while the vehicle runs on the track and allow the wheelset to rotate. It is therefore an extremely loaded component, with radial and axial loads (which are generated during

* Corresponding author. Tel.: +390110906952; fax: +390110906999.
E-mail address: nicola.bosso@polito.it

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curving and which can exceed 10% of the payload), which must allow a long distance without failures. Damage to the bearing can cause serious consequences on the vehicle, which can lead to derailment. For this reason, the bearing axle-box is subject to cyclical maintenance and inspections during service, to ensure the reliability and safety of the vehicle.

The bearing unit can suffer various types of damage, some related to normal wear and tear, and therefore progressive and inevitable, but predictable by means of damage models, others due to overloads or infrequent events and therefore difficult to predict.

From a structural point of view the damages can affect rolling surfaces and therefore the inner race, the outer race or the rolling elements. Other types of damage can affect the cage that drives the rolling elements or the lubricant used, which in the case of the railway vehicle is a specific grease for high-stress applications. Each type of damage can normally be identified from the initial phases by analyzing the spectrum of vibrations generated during rolling. In fact, the presence of a surface defect on one of the elements described above implies, during the rotation of the axis, the cyclical passage of the contact on the damaged surface. This produces an amplitude acceleration peak proportional to the severity of the defect, repeated with a frequency that depends on the rotation speed, the particular geometry of the bearing and the particular location of the defect (cage, rolling element, inner ring, outer ring).

The magnitude of the defect is destined to increase progressively with the mileage accumulated by the vehicle and is related to stress peaks that in the long run can compromise the functionality of the system, eventually leading to the formation of cracks and breakages of the parts that compose the bearing .

Furthermore, the damage can also be related to the removal of material (steel) from the bearing and its dispersion in the lubricant. The degradation of the lubricant can be related to the presence of impurities removed from the rolling or to other causes, such as infiltration of external contaminants or the simple loss of the lubricant properties for oxidation processes or other physical-chemical degradation mechanisms.

In any case, the degradation of the lubricant normally produces an increase in temperature during operation. The increase in temperature, if excessive, can in turn further reduce the properties of the lubricant and trigger a mechanism that, in a short time, leads to very serious damage to the entire axle-box, ranging from bearing seizure to shaft breakage .

The damage mechanism of the bearing, in the early stages, occurs with an anomalous vibration, detectable with the presence of spectral lines at the rotation frequencies typical of the damaged components of the bearing (cage, rolling races and rolling elements), as shown by Huang, et al. (2018), Liu, et al. (2018), Tang and Sun (2001), or with an increase in temperature. In any case, the final collapse of the component, even if linked to a mechanical break, manifests itself at the end with an high increase in the axle-box temperature and then lead to a catastrophic mechanical failure.

1.1. Axle-box bearing monitoring systems

Because of the criticality and importance of railway bearings mounted in the axle-box, these components are subject to careful maintenance and are constantly monitored with different strategies. Both onboard monitoring systems and wayside monitoring stations have been developed, as shown by Wilson and Frarey (1975) and Amini, et al. (2016).

One of the most common detection systems for bearing damage, due to its simplicity, consists in measuring the axle-box temperature. The measurement of the axle-box temperature can be carried out either with contact sensors mounted on the surface or inside the axle-box, or with systems positioned on the track, which measure using non-contact detectors, normally with laser or optical technology.

Thermal detection systems, although they are the basis of most fixed detection networks in the railway sector, are however often ineffective because, when the bearing exhibits an abnormal temperature, it is often close to its structural collapse. Therefore this type of detection can be used to discard wagons with damaged axle-box from service, but it cannot be conveniently used to support the maintenance process and in particular preventive maintenance. Moreover, if the detection is carried out with fixed stations, given the not always very frequent distribution of these detection points, it may happen that some axle-boxes in the distance between two successive detection stations lead to catastrophic failures.

Other monitoring systems based on accelerometric or acoustic measurements have been designed, also in this case they can be both onboard or fixed on the ground, as shown by Zhang, et al. (2018) and Peng, et al. (2018). Systems of this type require a more complex data processing strategy, but on the other hand they allow the detection of damage even in the early stages. They are therefore useful methods not only to discard the defective wagons, but also to assist the maintenance activities.

As stated previously, the detection systems can be fixed or mounted on the vehicle (onboard). The first type has mainly safety functions and is widely used to monitor both freight or passenger vehicles. Currently it is the only industrial system actually used for freight vehicles, which, not being electrified, cannot easily be equipped with on-board diagnostic systems.

However, onboard diagnostics have several benefits compared to fixed installations. First of all, they allow a continuous monitoring of the vehicle, and therefore allow to promptly detect both the conditions of damage to the components, and any anomalous behaviors of the vehicle that could possibly compromise safety. In addition, onboard systems can be used to monitor different aspects of the vehicle, not only the condition of the bearings, but also the conditions of the rolling surface of the wheels (which may include the presence of flats or polygonalization), damage to the suspension, braking system, or the event of derailment, as shown by Bosso, et al. (2018). Onboard systems can also be used to monitor the track and detect damaged locations, Bosso, et al. (2013).

In order to develop an effective monitoring system, it is essential to conduct an intense experimental activity, in order to develop the diagnostic algorithms. Experimental activity could also be developed on a train during service, but in this case the calibration of the system becomes more expensive and complex.

For this reason, it may be convenient to develop test benches capable of reproducing in the laboratory the behavior of the axle-box during normal service. The experimental tests on the track, performed on a real train, can still be useful, but it should be done once the system has been developed and preliminarily tested on a test bench.

This paper illustrates some possible test bench variants made at Politecnico di Torino, and used to develop and calibrate a railway monitoring system, with sensors positioned on the axle-box cover.

2. Experimental tests on railway axle-boxes

Testing on bearings is often carried out by means of test benches, which are firstly made by bearing manufacturers with the aim of guaranteeing the performances declared at the time of supply, in terms of service life and static or dynamic load capacity.

Historically, the first bearing test benches were therefore aimed at studying the bearing life, typically conducted under pre-established conditions. Also in the case of bearings used in the axle-boxes of railway vehicles, the bearing manufacturers have built ad Hoc test benches, used to carry out the bearing life tests. The test benches for the railway bearings are undoubtedly more complex to realize, due to the operating characteristics of the bearings: axle loads up to 25 tons (divided on 4 bearings), axial loads up to 3 tons, rotation speed over 2000 rpm (for high-speed vehicles).

The test benches made by the manufacturers allow to test the bearings mounted in the axle-box actually used on the vehicle. This is very important in order to recreate the same operating conditions in terms of the loads and geometric tolerances of the housings.

SKF has developed a test bench, called SKF R3 as described by Kure and Skiller (1997), to carry out the tests in accordance with the EN 12082 standard, and where it is possible to test two bearing axle-boxes simultaneously under conditions similar to those of operation. The bench is made according to the diagram of Fig. 1, and it is possible to provide a vertical or lateral load by means of hydraulic actuators. The system requires two additional supports to be able to discharge the applied load to the ground, while the motion is imposed to the main shaft by means of a central pulley and a belt system connected to an electric motor.

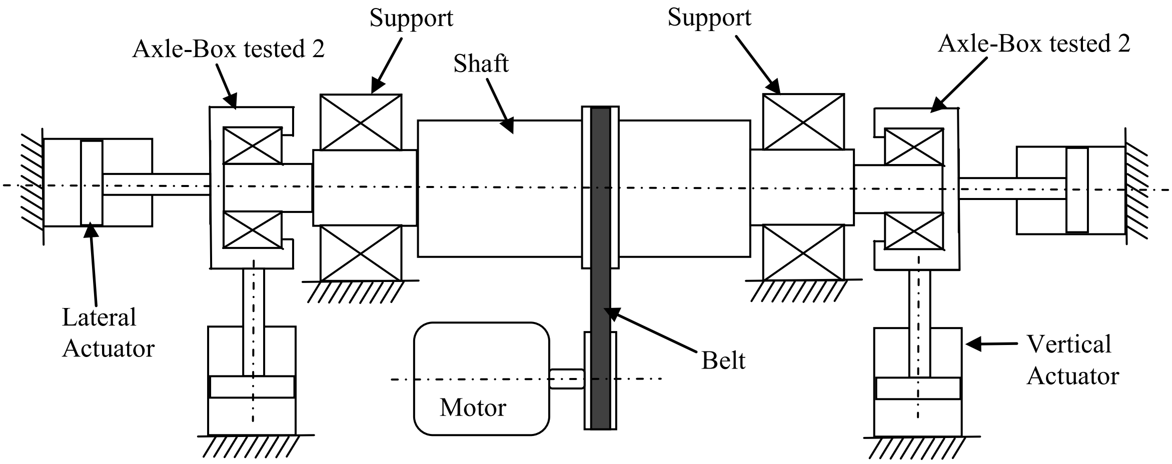

Fig. 1. Schematics of the R3 Test system developed by SKF.

Another test-bench was built by Schaeffler at the Industrial's Rail Test Facility in Schweinfurt, Germany, and allows testing up to 500 km/h, varying the lateral load and being able to simulate a contaminated environment, shown by Schaeffler (2013). Similar benches were built in China in relation to the bearing tests of the new high-speed vehicles, as shown by Huang, et al. (2018).

Some of these benches carry out the test using directly the assembled wheelset of the vehicle (DTR-W-30 test bench made by DanoblatGroup) or an entire bogie (DTR Dynamic train Bogie Test Rig, always made by DanoblatGroup). This type of benches can be conveniently used during periodic inspections of railway vehicles, possibly without having to dismount the vehicle.

The test-rigs described above are normally used by bearing manufacturers to guarantee the performance of their products, or supplied to the user of the vehicle to facilitate maintenance activities.

However, the development of new diagnostic systems requires test benches that can be used more flexibly to test new bearings or damaged bearings. Therefore, some universities and research centers have started to develop test benches to support their activities in the diagnostic field.

These benches do not necessarily need to be able to perform damage tests, which require a large load capacity and durability of the bench components. Instead it is very important that the bench is equipped with control and data acquisition equipment capable of analyzing the dynamic response of the tested bearings. It is obvious that to calibrate a diagnostic algorithm, it is necessary to analyze a bearing at different wear levels and with different types of damage, but it is not essential that such damage has been produced with the bench itself. In fact, it is possible to opt for tests with already damaged bearings, the damage of which has been artificially realized or in any case has been previously identified.

A test bench of this type is used at the University of Birmingham to identify bearing defects with different techniques, as shown by Amini, et al. (2016).

Another axle-bearing test is currently being built at the University of Southampton in collaboration with the Perpetuum Company Ltd. within the "WARNTRAK - Horizon 2020" project. This test will be used to develop innovative monitoring systems, Corni, et al. (2018).

3. Design of test rigs for axle-box testing at Politecnico di Torino

At Politecnico di Torino, several test benches were designed to support the development of vehicle monitoring systems. The developed monitoring systems are based on an instrumented axle-box cover, made in different variants to adapt to different types of railway axle-boxes. In addition to the axle-box cover, the system consists of a monitoring board that can be installed in the vehicle frame or on the bogie frame and which includes additional sensors and the acquisition and processing system for the detected signals.

The developed system was mounted on real vehicles and tested on the track under different conditions and on different vehicles, as shown by Bosso, et al. (2018) and Zampieri, et al. (2016). Nevertheless, the importance of having a laboratory test bench, where the system can be tested in a controlled environment and where various types of anomalies can be simulated.

The initial versions of the monitoring system have been tested on a very simple test bench, consisting of a single rotating axle-box bearing. Given the limitations of this type of bench, which does not allow to realistically reproduce the behavior of the axle-box during real service, it was decided to create a more complex test rig.

To realize this type of bench, however, several possible solutions were analyzed, starting from the benches created by the manufacturers of bearings and trying to modify them so as to obtain maximum versatility with a solution as simple as possible and reliable.

3.1. Single axle-box test-rig

The single-axle-box test bench, designed by the Politecnico di Torino, and illustrated in Fig. 2, consists of a real axle-box, which is rigidly fixed to the structure of the bench. In the case of freight axle-boxes such as the one shown in Fig. 2, fixing is carried out by means of two rigid tie rods, located at the spring supporting frames on the axle-box, and a central support, located on a plate fixed to the bench, where the top section of the axle-box is supported. In this case, the axle-box is mounted reversed, to facilitate fixing. The axle-box is locked on a portion of the railway axle, which includes the bearing seat, the shoulder and a part of the axle with wider diameter. From the opposite side of the axle-box cover, the axle, in correspondence with the portion in which it has been sectioned, is connected to a shaft with a smaller cross-section which is actuated by an electric motor.

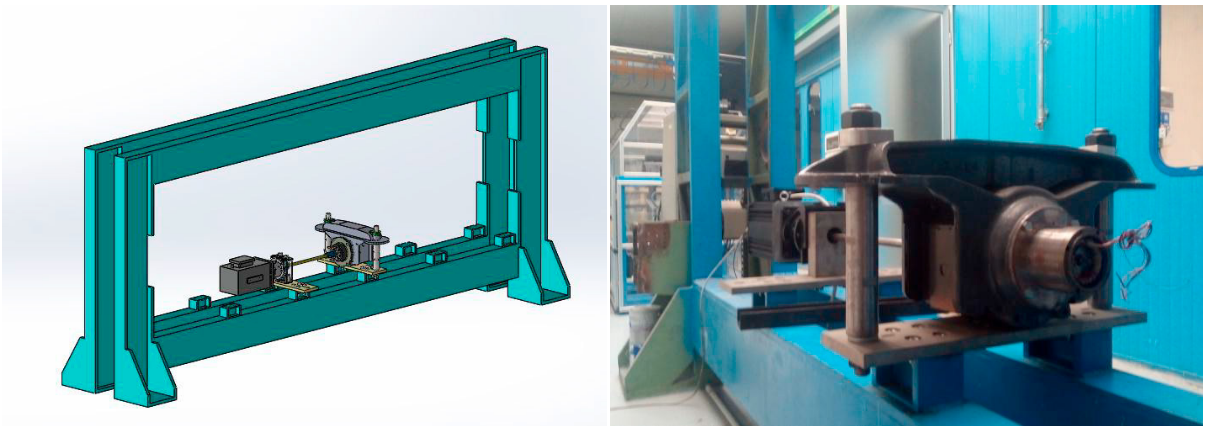

Fig. 2. Single Axle-box test rig, (a) Drawing; (b) Realized test rig with an instrumented axle-box cover.

It is evident that this type of bench does not allow to reproduce the loads applied to the bushing, but only allows it to be placed in rotation at different speeds.

Despite this limitation, this test rig was nevertheless used to carry out significant adjustments to the monitoring system. In fact, the accelerations useful for determining the damage to the bearings are detected in the longitudinal direction, because in this direction there is less overlap of the accelerations due to the irregularities of the track, and therefore an easier analysis of the acceleration spectrum produced by the bearing defects. In the longitudinal direction, however, there is also less influence of the vertical load, which in the case of this bench cannot be reproduced.

An important function of this bench, though very simple, is that of verifying the geometrical coupling, the seals and the functionality of the instrumented axle-box cover, before mounting it on the real vehicle, where any problems would cause a safety risk, or a failure of the test.

Furthermore, the developed monitoring system includes a trailing system which engages the preload screws of the bearings mounted on the axle. This system is used both for dragging the encoder, which is mounted on one axle-box for each wheelset, and for dragging an axis generator, which serves to power the monitoring system on freight vehicles, which are not electrified.

The setting up of the trailing system, from the mechanical point of view, is an activity that must be carried out accurately so as not to produce interference and possible breakages during the tests on the track.

3.2. 4 axle-box test-rig

In order to be able to draw more information from the bench tests, several solutions were analyzed to build a new test bench. The design objectives did not involve the necessity to design a test bench for prolonged tests, which could damage the bearing and follow its evolution.

The main purpose was instead to be able to test a new or damaged bearing in conditions as similar as possible to those of exercise.

So the main problem was to be able to apply the vertical load, which can have an influence both on the own frequencies, on the accelerations detected, and on the thermal behavior. In fact, the monitoring system that has been developed analyzes both the thermal and the accelerometric aspects simultaneously.

The first bench that has been studied is shown in Fig. 3; it has 4 identical axle-boxes, all of the type that must be tested. These axle-boxes are mounted at the ends of two shafts, which are pressed together by means of four tie rods, mounted on the axle-boxes in correspondence with the supports of the primary suspensions of the vehicle. The tie rods are then fixed to the structure of the bench in the lower side.

At the center of the two shafts two rollers are fixed, the diameter of the rollers is defined so as to keep a finite distance between the axle-boxes mounted on the two shafts when the load is applied to the tie rods. So the load is forced to pass through the rollers. On the rollers, twice the axle load is applied and therefore their length must be adequate to limit the Hertzian pressure.

The bench movement system is the same as the previous bench and acts only on one side of one of the two shafts.

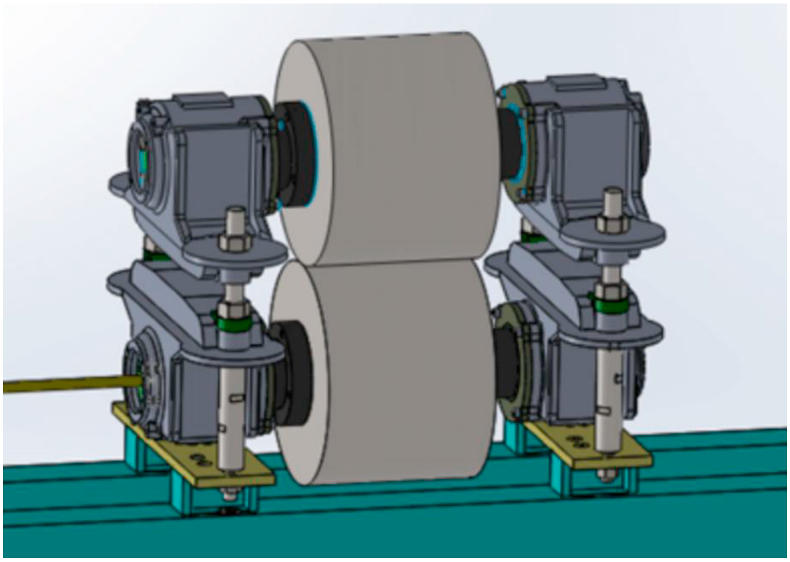

Fig. 3. Drawing of the test rig with four axle-boxes.

The advantage of this type of bench is to allow simultaneous testing of four bushings, and therefore of the entire monitoring system which is normally installed on a bogie. This is very important because to test the algorithms of a monitoring system, it is also necessary to evaluate the overall functioning that can be done only if the System is complete.

This bench does not allow the application of lateral loads, but this is not a significant limitation, because such loads are mainly developed on curves, and are smaller than vertical ones. The monitoring of the bearings while traveling on the real track, can be carried out more easily by discarding the sections in which the vehicle is running on curves, where there are other mechanisms that can make the interpretation of the results (relative to the bearings) complex. Obviously, the study of other phenomena, such as running stability, for example, instead requires analyzing lateral accelerations. But for this phenomenon a test rig of this type cannot be used.

The main problems detected for this type of bench are the presence of two large cylindrical rollers with high inertia placed in rotation and subject to high surface stresses.

Such rollers can create serious safety problems in case of breakage of the bench or its components, and therefore this make it an effective bench, but very dangerous for a University environment.

For its realization it would be necessary to build a set of shelters and building structures of considerable size, such as to greatly increase the costs of the bench and the complexity of use (assembly / disassembly of the bearings to be tested).

3.3. 3 axle-box test rig

The result was the definition of a new compromise solution, which made it possible to reduce safety issues and to allow service loads to be applied to the bearing.

The bench solution, currently under construction at Politecnico di Torino, is shown in Fig. 4 and Fig. 5. It is a three-axle-boxes bench, mounted on a single shaft (1). The two end axle-boxes are the ones to be tested (2), and are fixed to the bench in the same way as the first type of bench already made. The third axle-box (3), of a larger size, is mounted at the center of the shaft and is loaded with respect to the bench structure by means of two external tie rods (4). The motor system is the same used for the previous solutions and consists of an electric motor (5) of 650 Nm (maximum torque) and 3000 rpm (maximum speed), a motor support (6) fixed to the bench, and a transmission (7) which includes a double cardan shaft and a torque meter to measure the torque supplied.

The vertical load is applied manually by means of the driven nuts on the tie rods (4) that are threaded, and is measured by means of two ring load cells mounted under the nuts (8).

In the realized solution the used bearings are mounted on a shaft with 130 mm diameter. The central axle-box, in order to be mounted in the center must have a larger diameter, and in this case a suitable railway axle-box for shafts of 160 mm is used.

If there is the need to test 160 mm bearings, it is necessary to make a larger shaft and use a central axle-box non-standard for the railway sector.

The test rig built in this way allows, if necessary and without significant modifications, to apply axial loads to the external axle-box by means of an electromechanical or hydraulic actuator fixed to the structure of the bench. In the current phase it was not considered necessary to add this element, which is not of great importance for the tests to be carried out. The only disadvantage with respect to the bench previously analysed, is that in this case only two axle-boxes can be tested simultaneously (except to create two identical benches in series). However, the repetitive unit in the considered monitoring system is given by the one wheelset, and therefore the bench in this configuration is sufficiently complete to further develop the monitoring system. The assembly stages of the bench, with replacement of the axle-boxes, is particularly easy. Finally, the test rig does not involve criticalities from the point of view of safety.

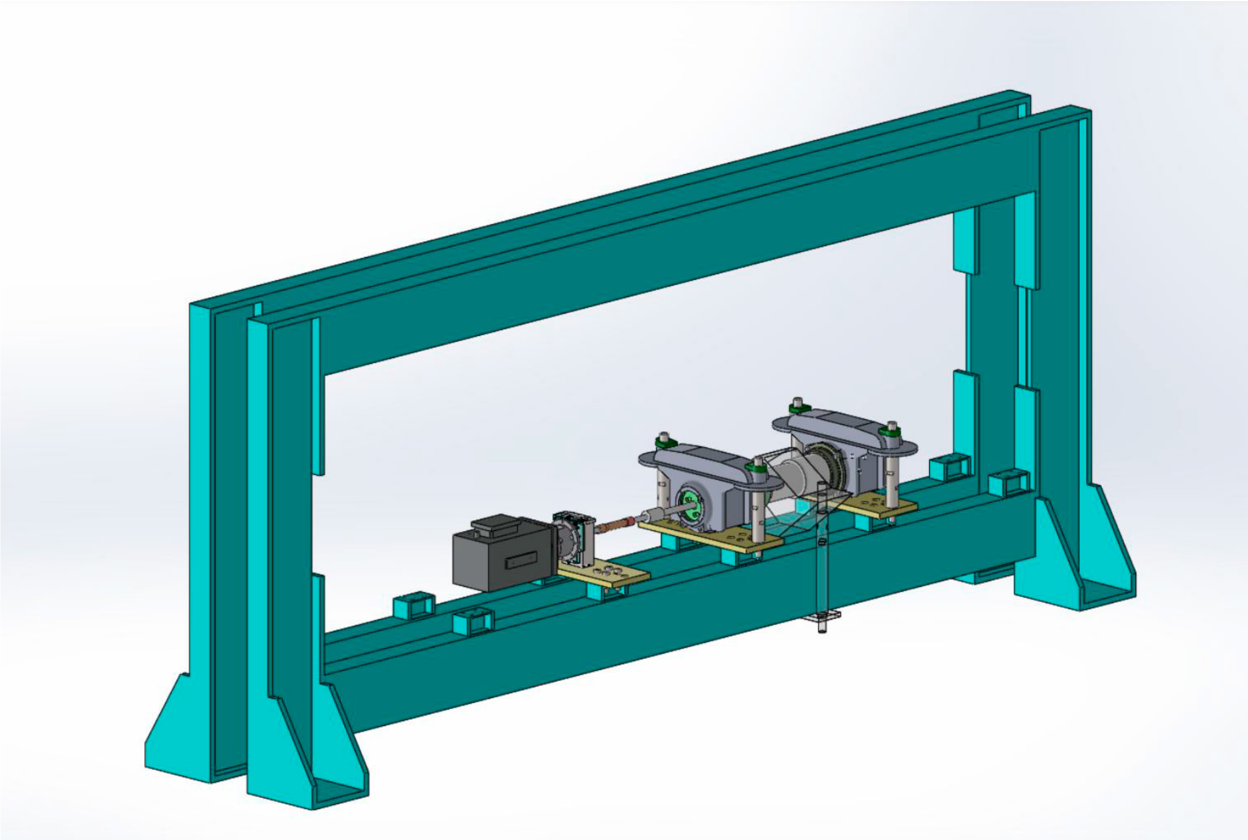

Fig. 4. 3D Drawing of the 3 axle-box test rig.

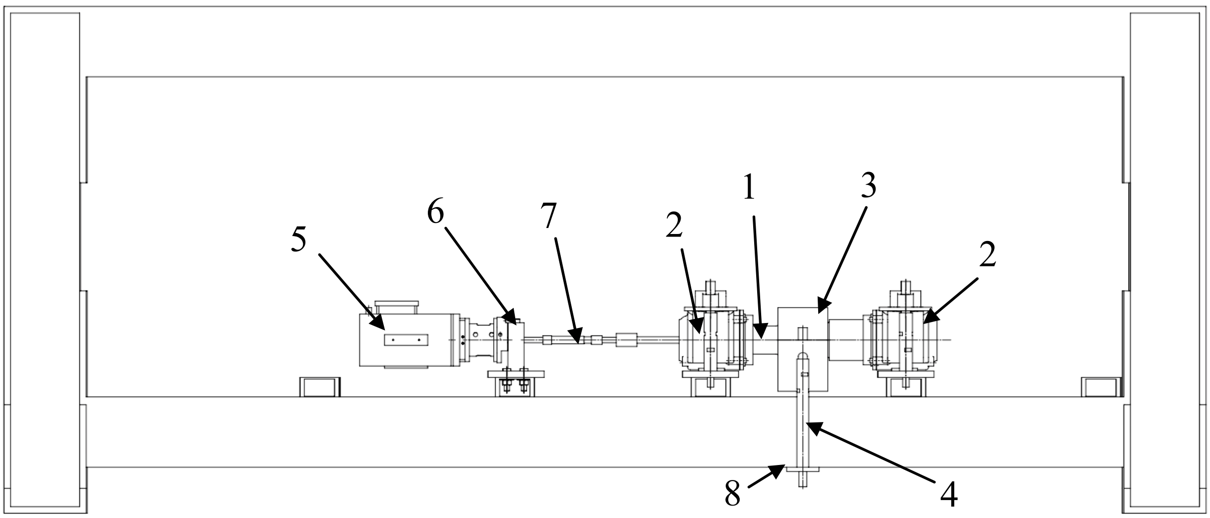

Fig. 5. (a) side view of the 3 axle-box test rig.

4. Conclusions

This work illustrated the characteristics of test benches suitable for carrying out the development and tuning of diagnostic systems to be installed on the axle-box of railway vehicles.

Existing test-rigs developed by different bearing manufacturers were analyzed, their main purpose is to produce the damage on the bearing and analyze the bearing life.

Starting from the strictly necessary requirements for the development of monitoring systems to be mounted in the axle-box, several solutions were analyzed to create a simple and effective test rig that can still serve the purpose. The test bench proposed in the last hypothesis, which is under construction at Politecnico di Torino, has considerable advantages, such as the possibility of reproducing the system mounted on a complete wheelset, with the possibility of applying the axle load and reproducing very high velocity in safety conditions. The proposed solution is simple and facilitates the assembly / disassembly operations during the replacement of the bearings to be tested.

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