Development of Laboratory for Testing of Railway Vehicles and Structures

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The aim of this paper is to elucidate the need for the establishment and continuous development of a laboratory for testing of railway vehicles and mechanical structures at the Faculty of Mechanical and Civil Engineering in Kraljevo. The development strategy of the Centre for Railway Vehicles and Structures Testing at the Faculty of Mechanical Engineering and Civil Engineering in Kraljevo is oriented in three directions. The first direction of development refers to high-quality and efficient teaching and education of students in the field of railway engineering and structures testing, at all levels of study. The second direction of development refers to the creation of conditions for the scientific and professional advancement of the members of the Centre and Laboratory, as well as their continuous improvement in accordance with the leading world trends. The third direction refers to the scientific work of the Centre and Laboratory, which includes the verification of theoretical solutions, designed and manufactured elements, sub-assemblies and assemblies of various types of constructions. In this way, it is possible to produce high-quality graduation, master's and doctoral theses, participation in domestic and international scientific research projects and cooperation with universities, institutes and the economy. The procurement and development of modern measuring equipment and software, as well as the equipping of a suitable space for work, were necessary as a prerequisite for the highest quality performance of the aforementioned tasks.

Keywords: Railway vehicles, Wagon, Laboratory, Kraljevo, Testing, Structures

1. INTRODUCTION

The history of designing, calculating and testing of mechanical structures in Kraljevo is directly related to the Wagon Factory Kraljevo. The Wagon Factory is also the initiator of higher education in Kraljevo and, together with the Faculty of Mechanical Engineering of the University of Belgrade, the founder of the Faculty of Mechanical Engineering Kraljevo. Within the Wagon Factory Kraljevo, a unit for experimental testing of construction was organized, whose founder and first head was prof. dr Ranko Rakanović (Fig. 1). Professor Rakanović was one of the founders and the first dean of the Faculty of Mechanical Engineering Kraljevo.

Figure 1: Prof. dr Ranko Rakanović, one of the founders and the first dean of the Faculty of Mechanical Engineering Kraljevo

During the multi-decade period, more than 200 railway vehicles and other structures were tested in the Test Center of the Wagon Factory Kraljevo (Fig. 2). All these tests were carried out in accordance with the valid domestic and international standards, on which appropriate reports and studies were prepared (Fig. 3), by which these constructions obtained permission for production and use.

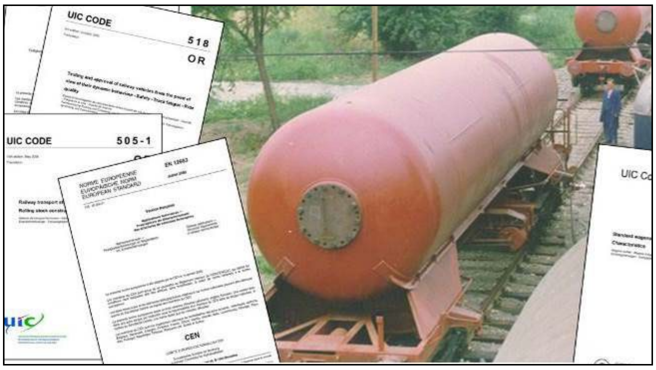

Figure 2: Impact testing of wagons according to international standards

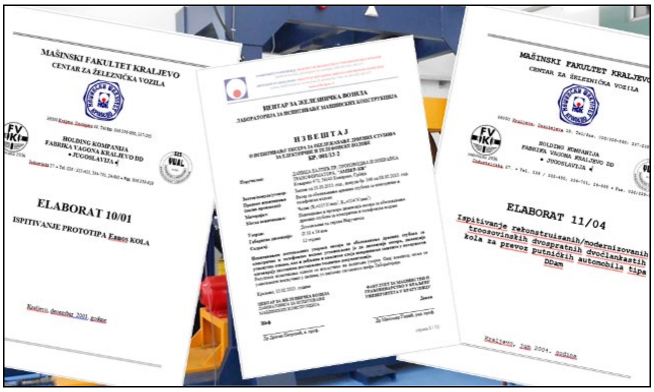

Figure 3: Reports and studies on the performed tests

In this way, the Test Center became one of the main pillars for evaluating and improving the quality of designed railway vehicles. In addition, during the design phase of new constructions, the Test Center became a very

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significant database on the behavior of similar, previously tested constructions.

2. PROCUREMENT AND DEVELOPMENT OF MEASURING EQUIPMENT

2.1. Establishment of Laboratory at Faculty of Mechanical Engineering Kraljevo

After many transformations in the 2000s and an unsuccessful sale to the Ukrainian company Azov-impex, the Wagon Factory Kraljevo was forced to go into bankruptcy, after which it was shut down. There was a real risk that half a century of knowledge, experience and developed equipment would be irretrievably lost. With this, the Faculty of Mechanical Engineering Kraljevo would lose space and equipment for scientific research and professional work and development in the field of railway engineering and structures testing. Seeing the danger of such a development, it was decided to establish a Laboratory for railway vehicles and structures testing at the Faculty of Mechanical Engineering Kraljevo (the latter Faculty of Mechanical and Civil Engineering in Kraljevo). Based on the experience gained, cooperation with the industry, as well as international and domestic projects, the aforementioned laboratory (Fig. 4).

Figure 4: Laboratory for railway vehicles and structures testing at Faculty of Mechanical and Civil Engineering in Kraljevo

One of the main directions of the future development of railway is based on the constant tendency to increase the safety and speed of railway vehicles running. In accordance with these trends, among the most important issues is solving the problems of safety and security of the most responsible parts of railway vehicles. It is well known that failure of vehicle parts such as wheels, axles or axle-bearings leads to failure not only a given wagon, but in most cases also the entire train. The consequences are unfathomable, with great material damage, and in many cases with human victims. That is why it is best to analyze, identify and eliminate the causes that lead to failures even at the stage of designing and manufacturing the railway vehicles.

2.2. Achieved results

2.2.1. System for measuring forces in wheel-rail contact

This measuring system is intended for continuous measurement of the lateral force *Y* and vertical force *Q* occurring in contact between the wheel and the rail and is characterized by wireless signal transmission. The system is based on the measurement of wheel strains using strain gauges placed in specially selected points, digitization of the measurement signal, radio transmission to the static electronic module in the box of the wagon, as well as on the appropriate processing of the received signals. The basic components of the system are: two instrumented wheelsets of the freight wagon equipped with strain gauges, an electronic computer unit for receiving and storing signals during measurement, and a computer module for processing and displaying measurement results.

Strain gauges are placed on monobloc wheels and their purpose is to measure strains caused by the effect of vertical and lateral force (Fig. 5). The position of placing the strain gauges was determined based on the calculation of wheel deformations using the finite element method (FEM).

Figure 5: Instrumented wheelset

The measuring points are arranged in 8 equally distant positions along the circumference of the wheel, with an angular distance of 45° (Fig. 6). Two groups of 8 strain gauges on one diameter are located on the outside, and two groups on the inside of the wheel.

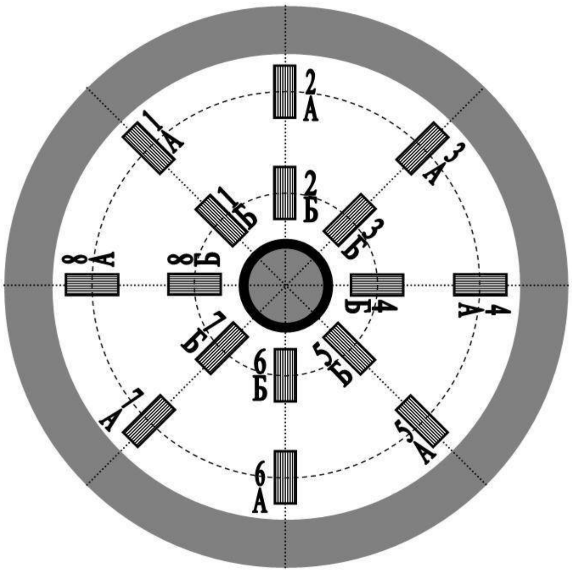


Figure 6: Arrangement of strain gauges on wheel

The transmission of measurement data from the rotating axle to the box in the measuring wagon is accomplished by radio communication using a special electronic module.

2.2.2. Test stand for calibration of instrumented wheelsets

The test stand provides the possibility of working with instrumented wheelsets in laboratory conditions with minimal testing costs. The basic function of the test stand is to simulate the contact between the wheel and the rail, i.e., the simulation of the forces *Y* and *Q* that arise in that contact.

The basic parts of the test stand are (Fig. 7): 1 – lower wheelset; 2 – horizontal movable support of the lower wheelset; 3 – upper wheelset (instrumented wheelset to be calibrated); 4 – vertical movable support of the upper wheelset; 5 – supporting structure; 6 – hydraulic systems for setting forces *Y* and *Q*; 7 – systems for registering the values of given forces *Y* and *Q*; 8 – motion drive; 9 – security systems; and 10 – control console.

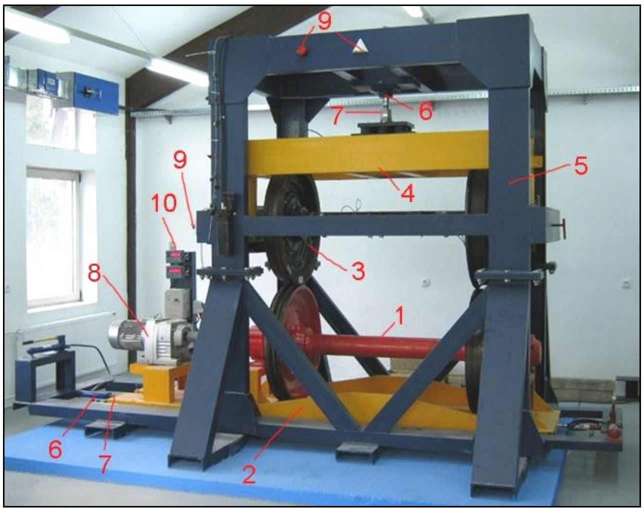


Figure 7: Test stand for calibration of instrumented railway wheelsets

The rail is simulated using the lower wheelset, while the function of the wheel is performed by the upper instrumented wheelset which is calibrated. The lower wheelset is machined so that the radii of rounding of the wheels profile correspond to the radii of rounding of the rail head profile (Fig. 8).

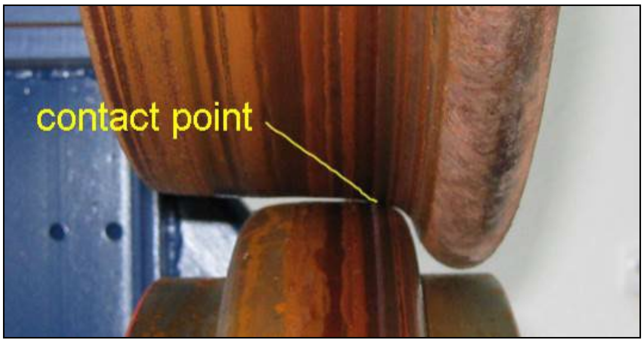


Figure 8: Imitation of rail head and simulation of wheel-rail contact on test stand

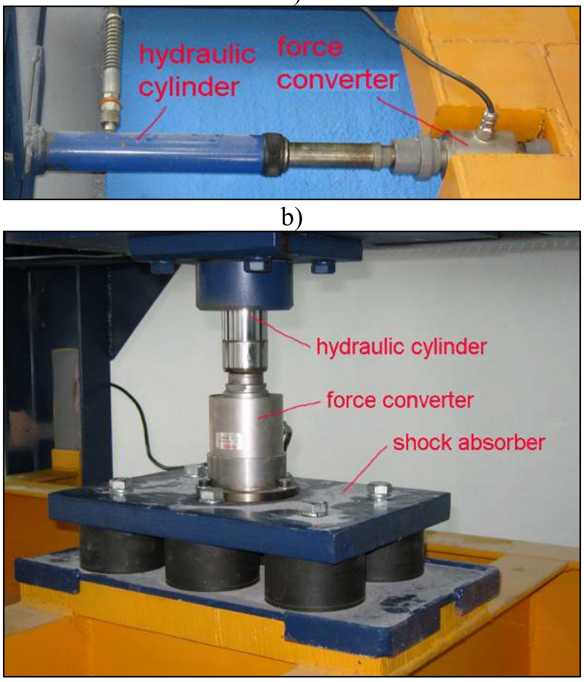
The test stand is equipped with hydraulic systems for loads setting in the vertical and lateral directions, up to 100 kN and 225 kN per wheel, respectively (Fig. 9).

The force is measured by the force converters (Fig. 10), installed in vertical and lateral directions in relation to the direction of action of the hydraulic cylinders.

During the calibration of the instrumented wheelset, the force values are read on the alpha numeric display (Fig. 11).

The motion drive is achieved by electric motor with a gearbox whose connection with the lower wheelset is realized through a cardan coupling (Fig. 12).

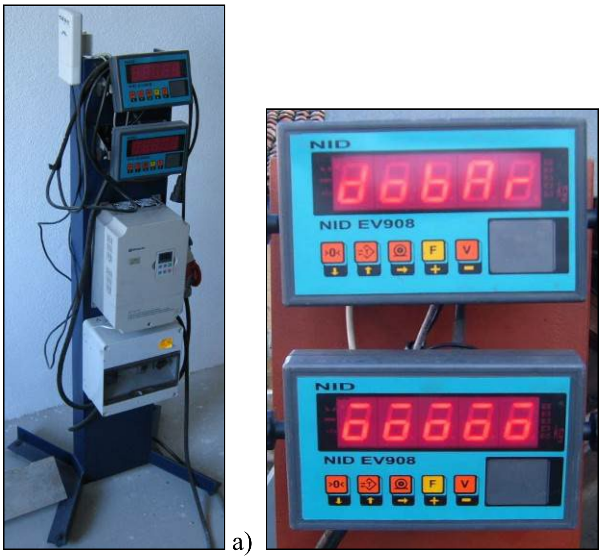
a)



b)

Figure 9: Hydraulic cylinders for loads setting in horizontal direction (a) and vertical direction (b)

Figure 10: Force converter



a) b)

Figure 11: Module with the main switch, frequency regulator (a) and alpha numeric displays (b) for reading the values of forces Y and Q

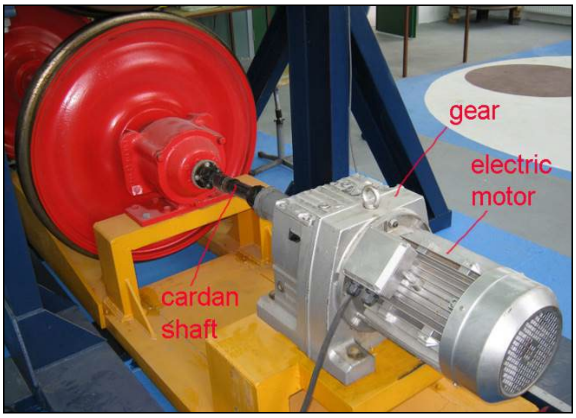


Figure 12: Motion drive with electric motor, gearbox and cardan coupling

Characteristic movements are horizontal movement of the lower wheeset that simulates the rail, and vertical movement of the upper tested (calibrated) wheeset. By the action of the hydraulic cylinder on the horizontal movable carrier, the entire system together with the lower wheelset is set in motion and creates a horizontal force in contact between the wheel and the rail – force *Y*. By the action of the hydraulic cylinder on the vertical movable carrier, this system together with the upper – tested (calibrated) wheeset moves downward and creates a vertical force in contact between the wheel and the simulated rail – force *Q*.

In this way, a laboratory simulation of the forces in contact between the wheel and the rail that occur during the movement of the railway vehicle on the track is carried out. The forces can be applied independently of each other, and the system allows changing the position of the contact point on the tread surface of the wheel. The test stand allows applying forces in the vertical direction up to 225 kN, and in the horizontal direction up to 100 kN.

The entire system is designed for the calibration of instrumented wheelsets for a normal track gauge of 1435 mm, and for working with wheelsets with an axle-load of up to 22.5 t. Assignment of forces *Y* and *Q* in the horizontal and vertical directions are provided with hydraulic cylinders driven by hand pumps. The detection of the values of the applied forces *Y* and *Q* is performed by using FLINTEC force converters, which are placed between the pistons of the hydraulic cylinders and the structures of the movable carriers of the wheelsets.

The rotational movement of the tested wheelset is realized indirectly via the lower wheelset that simulates a rail. The lower wheelset receives rotational movement via the cardan shaft, which is driven by an electric motor with a reduction gear. The power of the electric motor is 7.5 kW, and the regulation of the number of revolutions is achieved by means of a frequency regulator. The main switch, frequency regulator and alpha numerical displays for reading the values of forces *Y* and *Q* are placed on a special support that can be moved in the immediate area around the test stand.

The measurement signals obtained during the calibration of the instrumented wheelset are shown in Fig. 13.

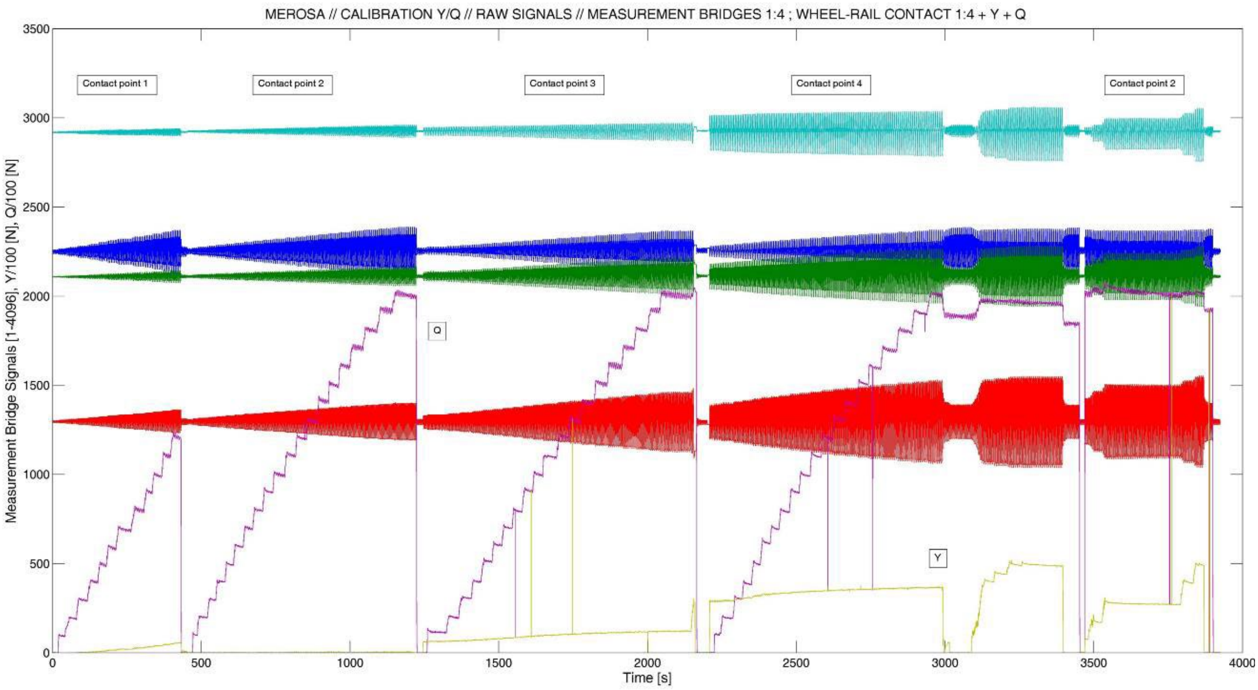


Figure 13: The measurement signals obtained during the calibration of the instrumented wheelset

The software package (Fig. 14) for adjustment of signal acquisition parameters serves for adjustment of parameters connected with acquisition of signals from strain gauges, such as resolution and speed of conversion, offset and signal intensification, temperature compensation, etc.

The procured measuring equipment classifies Centre and Laboratory for Railway Vehicles and Structures Testing at the Faculty of Mechanical Engineering and Civil Engineering in Kraljevo among very rare research centres equipped for the measurement of forces in wheel-rail contact by means of the telemetric transmission of signals. As for the education of students at the faculty, this equipment allows further development and improvement of practical teaching methods in the field of railway engineering. The equipment also enables further development and strengthening of research potentials of staff employed at Centre and Laboratory in accordance with the leading world trends. The most important scientific contribution is in the possibility of using the equipment for scientific-research purposes, primarily for development of new methods in treating the problems of measurement and identification of behaviour of freight wagons from the aspect of forces in the wheel-rail contact *Y* and *Q*, as well as their ratio *Y*/*Q*.

Figure 14: Interface of software package

2.2.3. Converter for measuring of lateral force and lateral acceleration

The converter for measuring of lateral force and lateral acceleration operates on the principle of converting the force into strain of the sensor elements installed on it. A special accelerometer with the measurement range of 5 g is also installed on it and it is used for measuring lateral acceleration (Fig. 15).

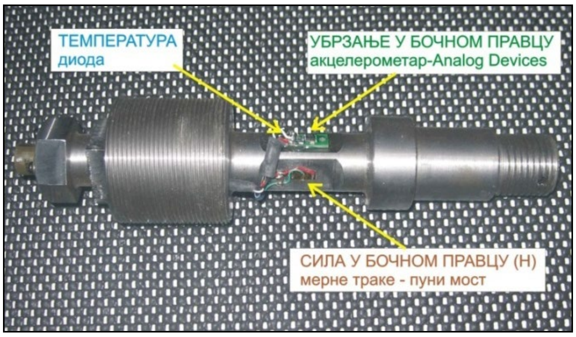


Figure 15: Converter for measuring of lateral force and lateral acceleration

2.2.4. System for measuring of height of wheel lifting

The mechanical assembly for measurement of the height of wheel lifting converts the height of lifting into the angular displacement of the legs which keep the sliders on the rail, on the front and bottom sides of the wheel. During the wheel lifting, the converter body lifts and the angles of both legs of the rail slider get reduced in relation to the normal (Fig. 16).

There are two angle converters in the converter, one for each leg, which measure the change of angle (Fig. 17). The angle converters are, the range of 20 degrees, and they produce analogue stress output in the function of angular position (Fig. 18).

Figure 16: Converter for measurement of the height of wheel lifting

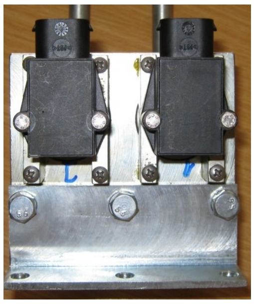


Figure 17: Angle converters used for measuring the change of angle of legs which hold the sliders

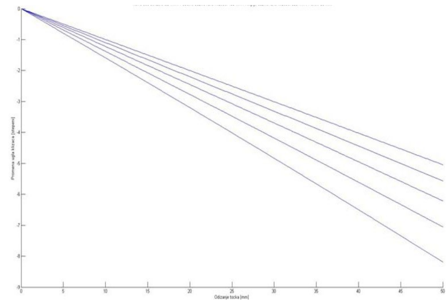


Figure 18: Change of angle of slider arm in function of wheel lifting height

2.2.5. System for measuring of compressing forces at the automatic coupling

The measuring system is intended for measurement of compression forces at the automatic coupling. A specially instrumentalized set of couplings type SA-3, which are installed on the wagons in front and behind the tested wagon in the measuring trains, was procured (Fig. 19).

Figure 19: Sets of measuring automatic couplings SA-3 with strain gauges installed

Two pairs of strain gauges are installed in the full measuring bridge at one of the couplings. Two strain gauges are installed in the direction of elongation at tension, and the other two are normal to the direction of elongation and they are used for compensation.

2.2.6. System for measuring lateral movements between test and barrier wagons

Measurement of lateral movements between test and barrier wagons is based on an optoelectronic vision system and image processing. Two CCD cameras are mounted on the test wagon and pointed towards the front end the rear barrier wagons whose buffers mutual position are to be measured, as seen in Fig. 20.

Figure 20: Measurement of lateral movements

An image of the target is acquired by a camera mounted on the front and rear sides of the test wagon. Field of view (FOV) of the camera points towards the target mounted on the barrier wagon whose buffer misalignment is to be measured. This wagon is marked with a cooperative target mounted across the gap and pointing towards camera. Target moves in direction lateral to the track following the motion of the wagon buffers and its image is acquired by the camera, using USB interface and processed by the onboard computer. The position of the target inside the field of view (FOV) of the camera follows relative position of the buffers, and is used to calculate the misalignment. Illumination is provided by a LED array and covers entire field of view (FOV) with monochromatic red light. Monochromatic light is used since it is possible to extract the red colour plane in camera and this limits total noise from external and background illumination to single colour. Illumination also provides for low level daylight or night operation.

3. CONCLUSION

Special attention in the European framework is paid to the development of the railway as a mass, safe, economical transport with the least harmful effects on the human environment. In the coming period, an even more significant investment in the development of railway transport is foreseen in order to increase safety, comfort, external and internal aesthetic characteristics, etc.

One of the most significant ways to increase safety is related to the development and introduction of a system for constant monitoring of the condition of the most important constituent elements of railway vehicles. This particularly applies to on-line monitoring of the state of the wheelsets (Fig. 21), on-line monitoring of the forces in wheel-rail contact and their ratio Y/Q, on-line monitoring of the temperature in axle-box bearings, as well as on-line monitoring of tracks condition.

In this way, it is possible to detect a malfunction immediately after its occurrence and to prevent an accident by reacting reacting in time. The research of these and similar scientific tasks has been facilitated by the development of laboratories such as Laboratory for railway vehicles and structures testing at Faculty of Mechanical and Civil Engineering in Kraljevo.

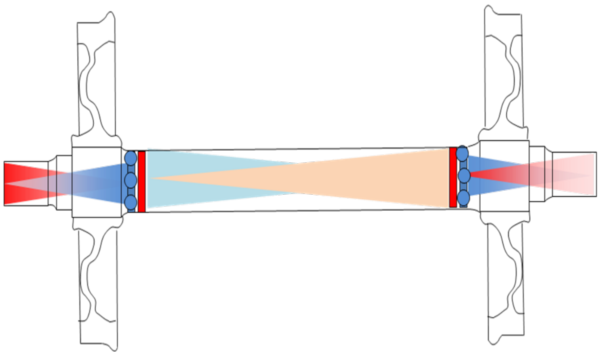


Figure 21: On-line monitoring of wheelset

Further development of this and similar laboratories will contribute to the achievement of the stated goals. The importance of the development of the laboratory is also reflected in the improvement of cooperation between the Center for railway vehicles and structures testing at Faculty of Mechanical and Civil Engineering in Kraljevo with renowned international and domestic institutions and scientists from this field.

ACKNOWLEDGEMENTS

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REFERENCES

[1] http://www.mfkv.kg.ac.rs/service/pages/tenders.php, in Serbian

[2] FP-7 Project SeRViCe, Grant agreement no.: 206929, Info day 2, 29/03/2010, Hotel ''Vila Aleksandar'' Vrnjacka Banja, Serbia, in Serbian

[3] D. Petrovic, A. Babic, M. Bizic, M. Djelosevic, Measuring equipment for dynamic and quasistatic testing of railway vehicles, Proceedings of the Scientific-Expert Conference on Railways – RAILCON 10, 07-08 October 2010, Nis, Serbia, pp. 177-180, ISBN 978-86-6055-007-3

[4] R. Rakanović, D. Petrović, Z. Šoškić, T. Simović, Ispitivanje mašinskih konstrukcija, Faculty of Mechanical Engineering in Kraljevo, 2006., ISBN: 86-82631-30-X, in Serbian

[5] International standard UIC 518, Testing and approval of railway vehicles from the point of view of their dynamic behavior - safety - track fatigue - ride quality, 4th Edition, 2009.

[6] International standard UIC 530-2, Wagons - running safety, 7th Edition, 2011.