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MODERN APPROACHES TO CONDITION MONITORING OF RAILWAY ASSETS

MODERNÉ PRÍSTUPY K MONITOROVANIU STAVU ŽELEZNIČNÉHO MAJETKU

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1 INTRODUCTION

Safety is most important in the process of organizing railway traffic. Railway traffic is performed using vehicles as mobile technical means and infrastructure as stationary technical means. These means are very complex and they consist of many different construction, mechanical, electrical and electronic elements. Each of these elements needs maintenance to keep functional condition. Maintenance can be performed sometimes, very often or continuously, but the maintenance activities must not suspend railway traffic, and traffic safety must be provided. Because of that, condition based preventive maintenance is performed in railway. Division of diagnostic systems in maintenance of railway vehicles are described in [1]. There are on-board and stationary diagnostic systems for monitoring of the railway vehicles condition. On-board detection systems are installed in a vehicle and are used for vehicle devices continuous monitoring in period of regular service. Stationary detection systems are used for a casual-periodic inspection of rolling stock and these are installed directly on the track or very near track and condition monitoring of vehicles is performed in time of regular operation, without stopping.

Many researchers deal with condition monitoring of railway vehicles. Vinberg et al. [2] compare some practical applications of diagnostic systems and types of sensors used for monitoring specific parameters. Description of different types of wayside detectors and evaluation of wayside condition monitoring technologies for condition-based maintenance of railway vehicles is presented in [3]. Ngig et al. [4] compare the modern techniques used for condition monitoring of railway vehicle dynamics by analysing the advantages and shortcomings of these methods. Furthermore, research by Zheng [5] is performed to improve rolling stock and infrastructure reliability, availability, maintainability, and safety,

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through the development a novel remote condition monitoring system based on the integration of acoustic emission and vibration analysis. Using the collected information from on-board diagnostic systems it is possible to analyse the condition of the vehicle components, but also the condition of the railway track. Tsunashima et al [6] describe the tests that were conducted in Japan Railway to research the possibility of condition monitoring of railway track using in-service vehicle. This track-condition-monitoring system is based on measuring the vertical and lateral acceleration of the car body, as well as measuring noise in vehicle cabin. Results of the field tests showed that the condition monitoring of railway track using the developed probe system provide the useful information for condition-based-maintenance. Paper [7] investigate the measuring of transversal position of the wheels on the track in running condition. Using the onboard high-speed stereo camera system can perform defects identification of the wheel and the track (such as deformation of rail head edge, lateral wear, worn wheels, cracks in wheel and rail, corrugation, and other irregularities). Hodge et al. [8] describes the research of wireless sensors network technology for monitoring in the railway industry for analysing systems, structures, vehicles, and machinery. In recent years sensor devices have become cheaper, thus leading to their rapid expansion in condition monitoring.

Diagnostic of railway vehicles and infrastructure condition is the most important activity of railway maintenance and traffic safety. This paper describes current methods of diagnostic failures of railway technical means. Furthermore, paper presents the undercarriage railway inspection robot developed at Faculty of Mechanical engineering, University of Niš.

2 MAINTENANCE DIAGNOSTIC METHODS IN RAILWAY

Condition monitoring is the basic part of technical means maintenance. The maintenance of railway vehicles includes the inspections implemented on daily basis before, during and after the performed transport and it represents the permanent monitoring. New types of railway vehicles are equipped with modern diagnostic systems, and maintenance interventions are based on the data from the sensors during operation. Monitoring of railway infrastructure, especially the track usually is performed by observation and by measuring certain parameters using the special measuring vehicles. Monitoring of the railway vehicles condition can be performed by on-board diagnostic systems and by stationary diagnostic systems. One of the challenges with implementing condition monitoring is to establish the right diagnostic method, since reliable measurements are necessity for successful condition monitoring. Relevant and correct measuring parameters should be determined to provide the most relevant measuring data, that can then be used as decision support in the maintenance management process. Most of the condition-monitoring systems for railway vehicles are focused on the wheel and bogies. Derailment of the train can appear caused of wheels damage, and the early detection of wheel failures is essential for the railway safety. It is important to monitor the condition of wheel-rail contact to avoid accidents, as a derailment and possible injuries.

2.1 On-board detection of vehicle condition

On-board systems are installed on the vehicles, and they are used for vehicle's components continuous monitoring in regular service. On-board diagnostic system is often aimed at monitoring vehicle running gears using the sensors for measuring the temperature, vibration, pressure, force, etc. Vehicle assemblies, which are in permanent contact with the infrastructure, as pantograph with catenary and wheel with rail, are the most loaded and exposed to wear. Because of that, on-board diagnostic systems for continuous monitoring of these assemblies are developed. Image of contact pantograph-catenary in running condition obtained by an infrared camera mounted on the roof of the locomotive is presented in ***fig. 1***.

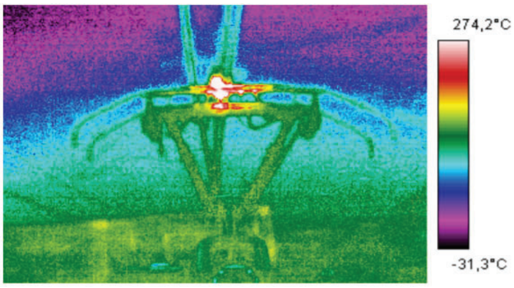

***Fig. 1** Thermal image of pantograph-catenary in operating condition [10]*

***Obr. 1** Tepelná snímka pantograf-trolej v prevádzkovom stave [10]*

Acceleration sensors are installed on the modern locomotives/trains for monitoring the vibrations. The rolling stock accelerations measurement system consists of sensors which are installed on body, bogies and axle box. Measuring data are integrated with speed values and with the train location on the railway line. On-board diagnostic system of ICE trains, among others, contains of eight acceleration sensors per single bogie, for measuring the bearing and bogie frame vibrations (***fig.2***) [1].

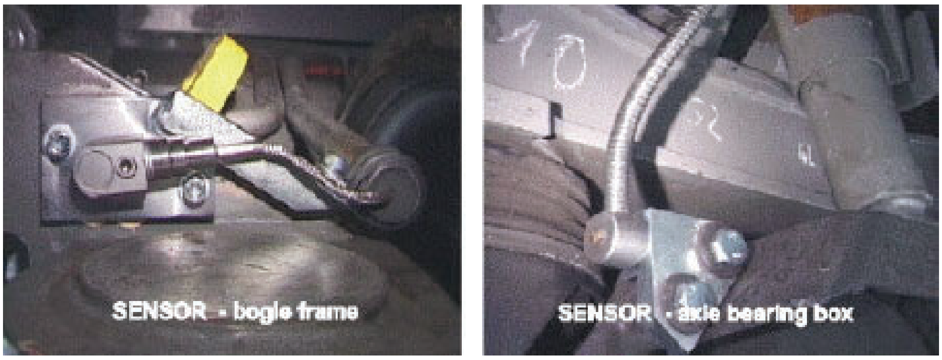

***Fig. 2** Accelerometers placed on bogy frame and axle box on ICE trains [1]*

***Obr. 2** Snímače zrýchlenia umiestnené na ráme podvozku a nápravové ložisko na vlaku ICE*

Acceleration measurements are used to evaluate ride comfort and vibration transmission from axle boxes to bogies (primary suspension), and from bogies to the vehicle body (secondary suspension). Kawasaki developed on board Bogy Instability Detection system (BIDS) active suspension system that improves passenger comfort and ensure safety and running stability. Such systems provide effectively maintain bogies and tracking system and significantly reduce track maintenance costs [11]. The main task of active suspension system is to detect vehicle vibration using sensors and to generate some force on electric actuator mounted in connection of bogie and vehicle body to cancel out vehicle vibration (***fig. 3***). This system has been adopted in Shinkansen train and other highspeed vehicles.

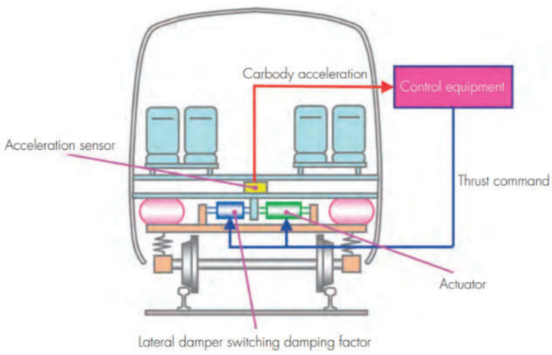

***Fig. 3** Active suspension system [11]*

***Obr. 3** Systém aktívneho vypuženia*

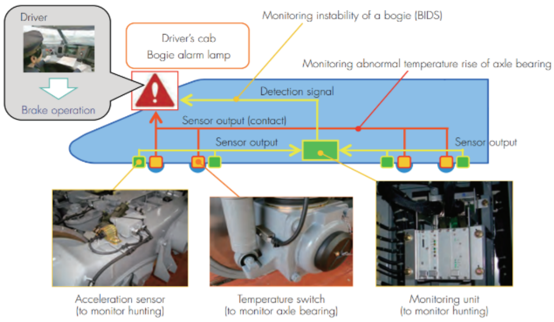

Fig. 4 *System configuration of BIDS [11]*
Obr. 4 *Konfigurácia systému BIDS*

The BIDS system includes an acceleration sensor, mounted on a bogie frame, which measures lateral vibration and, in this way, detects hunting at the monitoring unit. Measured data are notified to the driver who safely decelerates the vehicle. Drive transmission systems are monitored mainly by the temperature sensors, and abnormal rises in temperature are directly notified to the driver's cab (***fig. 4***). In addition to these vehicle components, on-board diagnostic systems are widely used in assemblies such as diesel engines, electromotors, brake systems, etc. Diesel and electric motors are one of the most expensive parts of railway vehicles, and periodic inspection is not the most convenient procedure. Continuous monitoring is the better solution, and this approach allows maintenance when it is necessary. A failure diagnosis can greatly predict the time required for repair. Rolling stock brake system is of great importance for safety. In most cases, when train drivers report any problem with brake system in running condition, it is difficult to reproduce failure when the vehicle is in stationary state in the depot. Because of that, real-time monitoring is much more effective, so "recording" the braking cycle and monitoring the wear of the brake pads can give indications of failure in the development phase. Such a failure detected at an "early stage" is much easier to eliminate and it enable lower maintenance cost.

2.2 Stationary diagnostic systems of vehicle condition

Stationary diagnostic systems are installed in depot or near the rail. If these diagnostic devices are installed in the workshop, then the condition of certain vehicle assemblies that are excluded from traffic is determined, as part of the inspection. If the diagnostic devices are installed on a regular route, directly to the railway, then the monitoring of certain vehicle assemblies is performed within the framework of regular operation, without stopping. To make inspection in depots more successful and to perform them in shorter time, specific diagnostic systems were developed such as TrainScanner developed by Alstom and shown in ***fig. 5*** [12]. While the train is passing through the stationary measuring devices with a small speed, numerous vehicle parameters are measured and recorded.

There are different types of wayside detectors as: detector for train gauge measurement, hot bearing detectors, wheel impact load detectors, overload and imbalanced load detectors, truck performance detectors, wheel profile detectors, hot wheel detectors, acoustic bearing detectors, etc. Main advantage of these methods of condition monitoring of vehicles is that they are performed within the regular operation, without train stopping. In addition, the advantage of wayside detection is that one

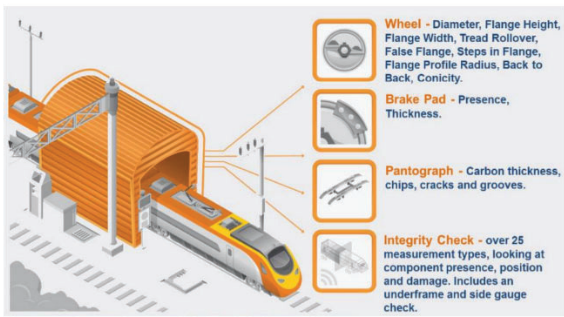

Fig. 5 *Alstom TrainScanner [12]*
Obr. 5 *TrainScaner Alstom*

detection system is used for all vehicles on that line, which is very rationally. The guide [13] reviews the most common wayside detector systems in North America’s rail network that are used to inspect and monitor rolling stock condition, particularly in terms of the wheel and rail related defects and irregularities. These wayside detectors are [13]:

- TADS - system for acoustic identification of bearing defects (total 19 devices);
- HBD – hot bearing detection (more than 6000 devices along freight network);
- HWD – hot wheel detection (most of them are integrated with HBD);
- TBOGI – detection system for measuring of geometric performance of car bogies (28 devices);
- THD – truck hunting detection system using strain-gages or laser-based (total 94 devices);
- TPD - system for evaluating the suspension performance of bogies along S curve section of track (total 28 devices);
- WILD – system for detecting the wheel defects like flat, thermal cracks or other analyzing the wheel impact loads (total 185 devices);
- WTD – system for detecting hot wheel due to locked brake and cold wheel due to inoperative brake system using infrared technology (more than 700 devices).

Fig. 6 *Acoustic detection system [1]*
Obr. 6 *Systém akustickej detekcie*

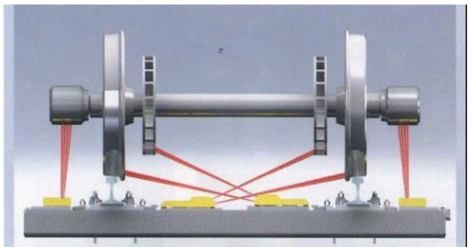

Fig. 7 *System for detection of preheated wheels, bearings and brake discs [14]*
Obr. 7 *Systém detekcie prehriatych kolies, ložísk a brzdových kotúčov*

Acoustic detection systems are preventive systems for axle bearing maintenance developed to identify bearings with internal defects in the early stages of failure. System consists of a series of microphones placed near the track that record data about the soundtrack of each axle bearing (***fig. 6***).

Hot bearing detectors are the most common wayside detectors in many railroads worldwide. But measuring of wheel and brake disk temperature is also applied. The system presented in ***fig. 7*** uses thermal imager technology. This system consists of three modular scanners covering wheels, axle bearings and brake discs.

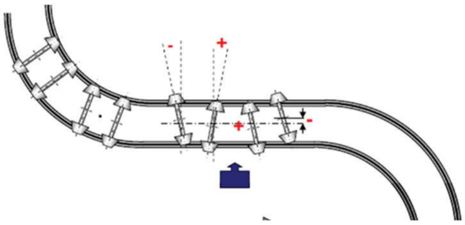

Fig. 8 *T-BOGI detection system [15]*
Obr. 8 *Detekčný system T-BOGI*

An example of T-BOGI (optical control of bogies geometry) of the Canadian company WID is presented in ***fig. 8***. This product is an optical monitoring system for measuring the angle of attack and the lateral position of the wheels in relation to the rail. The system uses a laser and camera to measure the position of the wheel axle.

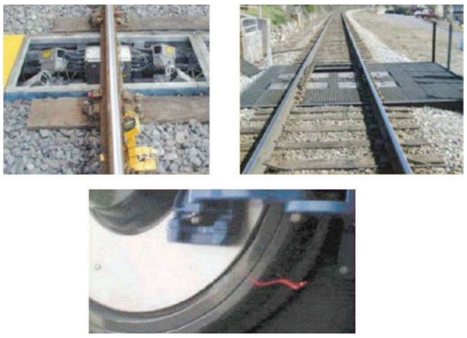

***Fig. 9** System for laser-based measurement of wheel profile [1]*

***Obr. 9** Systém na laserové meranie profilu kolesa*

Laser and camera wheel profile measurement technologies are methods of non-contact wheel condition measurement. ***fig. 9*** shows a system for laser measurement of wheel rim profiles. The laser-obtained images are automatically processed by computers to extract the wheel profile (***fig. 10***). It is possible to measure parameters such as: the thickness of the wheel rim, damage to the running surface of the wheel and the height of the rim. The ability to predict the wear of each wheel individually allows the maintenance service to plan proactive wheel maintenance to ensure the maximum life of the wheel axles [1].

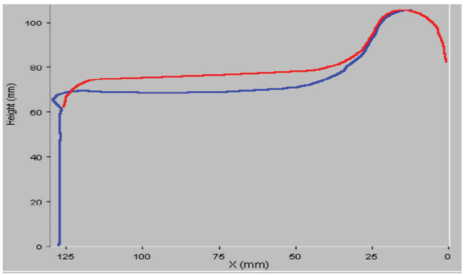

***Fig. 10** Display of measured and standard wheel profile [1]*

***Obr. 10** Zobrazenie meraného a štandardného profilu kolesa*

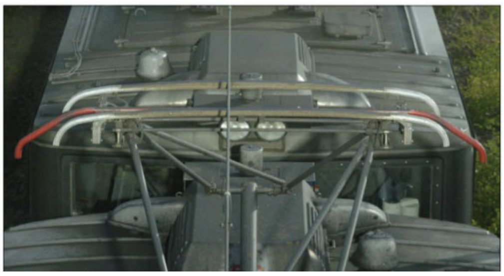

***Fig. 11** Pantograph monitoring system [16]*

***Obr. 11** Systém monitorovania pantografu*

The pantograph damaged carbon strips cause additional stress on the contact wire, which can cause the break of the contact and break in rail traffic. The pantograph monitoring system (***fig. 11***) monitors the condition of the carbon strips in pantographs on electric traction units [16]. The pantograph monitoring system (***fig. 11***) includes a radar, a flash unit and a camera. The radar detects an oncoming train and recognizes its speed, distance and direction of travel. The camera can capture all active pantographs on the train.

2.3 Detection of railway infrastructure condition

Railway infrastructure management performs regular track and overhead contact line inspections to maintain and improve safety, reliability, and comfort. There are different diagnostic methods. Main diagnostic systems include in infrastructure condition monitoring are: track measurements (track geometry, rail profile, rail corrugation, etc), overhead line measurement (geometry measurement, contact wire wear, pantograph interaction, electric parameters, etc), vehicle dynamic measurement (ride quality, axle boxes/bogie/body vibrations, wheel/rail contact, etc), visual inspection (rail surface defects detection, overhead line defects detection, train gauge, etc) [17].

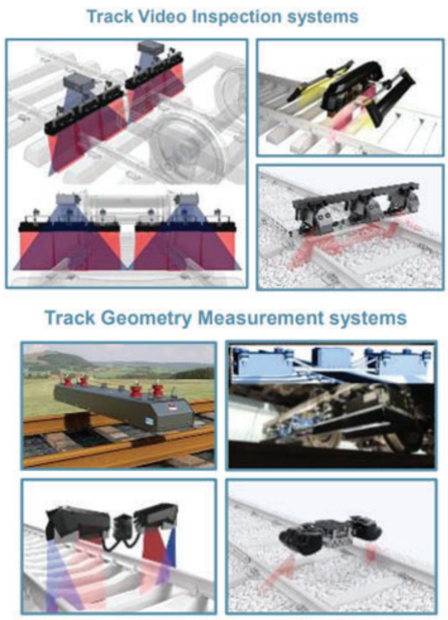

Fig. 12 *System for train gauge control [12]*
Obr. 12 *Systém na monitorovanie parametrov koľaje*

Infrastructure managers use specialized track monitoring vehicles with a variety of advanced measurement equipment which are used to inspect the rail, on annual or semiannual infrequent basis. Deformation of rail head edge, such a lateral wear, worn wheel bandages, variations in width of rail and other irregularities, lead to increase of lateral forces in the track. By passing the measurement vehicle on a certain track section and performing measurements, a software package analyses the measured data and generates a inspection report. The diagnostics car is usually equipped with diagnostics measuring systems which consist of ultrasonic and eddy-current equipment. Authors in the paper [18] described visual inspection of rails, ultrasonic and eddy current testing methods for detection of surface defects, which are in use in DB. The ultrasonic inspection is applied on railway tracks primarily for detection and evaluation of internal rail defects. The basic configuration of the ultrasonic technique on DB inspection trains consists of beam transducer with 0°, 35°, 55° and 70°. Alstom have been also developing a system called “TrackTracer”, wherein equipment fitted on service trains provides monitoring of the infrastructure. This system currently uses cameras and sensors to monitor overhead line and rail condition, geometry and quality (***fig. 12***).

3 AUTONOMOUS ROBOT FOR TRAIN UNDERCARRIAGE VISUAL INSPECTION

Fig. 13 *ATUVIS positioned on the track, below the train*
Obr. 13 *ATUVIS umiestnený v koľaji pod vlakom*

Autonomous robot for train undercarriage visual inspection - ATUVIS [19] is currently TRL8 patent pending solution developed within consortium of CAM Engineering d.o.o, Faculty of Mechanical Engineering, University of Niš and Institute Mihajlo Pupin, University of Belgrade. ATUVIS represents an innovative solution to boost further digitalization of the processes in the railway industry. ATUVIS as autonomous robot that is replacing the traditional way of visual undercarriage visual inspection performed by humans in the inspection pit. ATUVIS can carry out a full visual inspection directly on a track by moving the robot below the stationary train as shown on ***fig. 13***. In such way it is not necessary to transport the train to the inspection pit which provides significant operational costs reduction.

The innovative system encompasses two components: hardware (autonomous robot) and software (based on Artificial Intelligence) for visual inspection and defects identification. The robot caries high quality action camera that can be moved in direction perpendicular to the track and rotated about vertical and horizontal axis. Such technical solution enables positioning of camera to any position below the train (***fig. 14***). The components are photographed with camera and than processed by artificial intelligence to identify changes from the nominal state (***fig. 15***). Beside robot localisation by odometry and Inertial Measurement Unit (IMU), ATUVIS use cognitive positioning/machine recognition of undercarriage components to position itself for image acquisition. ATUVIS robot can move and autonomously maintain direction in the limited space between track on rough terrain due to sleepers and broken stone tamping. It is completely wireless controlled robot equipped with four motors connected to traction wheels which allows the robot to slightly change direction and to follow pathway between tracks. All the acquired images are stored in the cloud which enables tracking of component state over time and planning of maintenance based on actual condition of the components

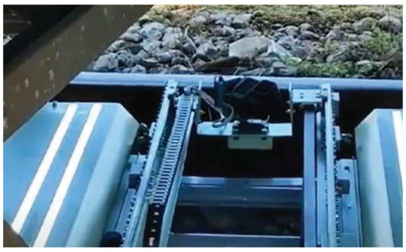

Fig. 14 *Camera positioning below the train*
Obr. 14 *Kamera umiestnená pod vlakom*

Fig. 15 *Identification of defect*
Obr. 15 *Identifikácia defektu*

4 CONCLUSION

The most effective maintenance of railway vehicles and infrastructure is a continuous control their condition without interrupting operation. There are different diagnostic methods applicated in railway, like visual inspection, geometric measurement, temperature measurement, acoustic measuring, force measuring, etc. Vibration measurement is a method that is increasingly used in technical diagnostics in last time. Continuous measurement of vibrations while running with precise GPS positioning of the vehicle on the track can be significant indicators of the vehicle or the track condition. In this way, the occurrence of a defect can be determined at an early stage, and adequate maintenance activity can be undertaken. In this way, railway safety can be improved. Accelerated development of technologies has led to the application of very advanced diagnostic systems on the railway. Each of them has certain advantages and disadvantages. Therefore, modern maintenance should be based on the use of different diagnostic methods, and decision can be made comparing their measured data. Such robotic system for autonomous identification of undercarriage defects and condition monitoring is briefly presented in this paper.

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Summary

The permanent condition monitoring of railway technical means condition is the basic maintenance activity, and it is essential for the safety of railway traffic. Infrastructure managers are responsible for correctness of track and other infrastructure objects and railway operators are responsible for operational availability of trains, and according to that, these railway undertakings must perform maintenance of their technical means. There are on-board and stationary diagnostic systems for monitoring of the railway vehicles condition. On-board systems are installed on the vehicles and stationary diagnostic systems are placed on the track or near the track. But some sensors of on-board diagnostic system can be used not only for measuring the vehicle performances but also for detect track irregularities. This paper describes methods of condition monitoring of railway technical means which are in use on railway today. The paper also presents an undercarriage railway inspection robot, developed at Faculty of Mechanical Engineering, University of Nis.

Resumé

Trvalé sledovanie stavu technických prostriedkov železníc je základnou údržbárskou činnosťou a je nevyhnutné pre bezpečnosť železničnej dopravy. Manažéri infraštruktúry

zodpovedajú za dobrý stav tratí a ostatných objektov infraštruktúry a dopravcovia zodpovedajú za prevádzkovú dostupnosť vlakov a podľa toho musia títo dopravcovia vykonávať údržbu svojich technických prostriedkov. Na monitorovanie stavu železničných vozidiel sú k dispozícii palubné a stacionárne diagnostické systémy. Na vozidlách sú inštalované palubné systémy a na trati alebo v blízkosti trate sú umiestnené stacionárne diagnostické systémy. Niektoré senzory palubného diagnostického systému však možno použiť nielen na meranie výkonu vozidla, ale aj na zisťovanie nepravidelností trate. Tento článok popisuje metódy monitorovania stavu železničných technických prostriedkov, ktoré sa dnes na železnici používajú. Článok tiež predstavuje robota na kontrolu podvozkov železníc, vyvinutý na Strojníckej fakulte Univerzity v Niši.