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Train control system for railway vehicles running at operational speed

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ABSTRACT

Purpose: : Bulgaria's accession to the transport system in European Union as well as the strategic geographic location of the country suggests a high level of operational reliability in the rail sector. This paper contains a detailed study aimed to investigate the advantages and disadvantages of the Checkpoint Systems implemented by leading railway administrations.

Design/methodology/approach: The basic principles of the construction of Checkpoint Systems are examined and the purpose of corresponding regional system for control of the train technical state in motion in Bulgaria is defined. The possibilities for the application of different types of sensors in order to achieve necessary and sufficient features for reliable implementation at a relatively low price were analysed.

Findings: A model for values comparison of the most important parameters is proposed. The Recognition System is based on intelligent optical sensors that operate through cameras mounted on certain height which scans the numbers of wagons and after subsequent software image processing it compares them to the numbers from database.

Practical implications: Application of these systems increases safe movement of trains and regulates the superintendence between the infrastructure operators and managing infrastructure state institutions.

Originality/value: The novelty in this authors' approach is the use of accelerometer sensors measurements that examines the magnitude of acceleration acquired by the rail under the effect of shock cyclical loads. Thanks to achievements of modern communication and information technologies, the key aspects of creating technical connections are marked. This research indicated the guidelines for the development of a nationwide unified network of diagnostic points which will help the future studies.

Keywords: Technical devices and equipment; Train control system; Railway vehicles

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MANUFACTURING AND PROCESSING

1. Introduction

Harmonisation of technical and operational specifications for the trans-European rail system is vital for free movement of trains and related equipment in the European internal market. The interoperability directives, together with European legislation opening up the rail market to regulated competition, are key factors in increasing the rail sector's productivity and in making this sector more competitive relative to other transport modes [1, 10]. The need for European Train Control System - ETCS stems from EU Directive 96/48 about the interoperability of high-speed trains, followed by Directive 2001/16 extending the concept of interoperability to the conventional rail system [14].

The train control system requires two sets of data to execute accurate train operation. One set is static data, such as rail parameters, locomotive traction force and braking capabilities, etc., which is closely related to the train model [11, 12]. Another is dynamic, such as train position, speed, and motion states. It is a key mission to obtain and provide the train control system with these two sets of data in real time.

The idea to develop systems for control on train movement utilizes the opportunities provided by the advanced level of computer technology to monitor the process of interaction train-track interaction [8]. The experience of the railway administrations in Europe and worldwide to implement such systems has proved a significantly better economic effect of transport operation. The results have shown that investments are expedient. The advantage of their implementation has the following aspects:

- Control on cargo location;
- Optimal load distribution on the railway network;
- Accurate determination of infrastructure charges;
- Better organization of repairs of railway vehicles based on their current state;
- Prevention of emergency and the damage it has caused.

A team of researchers from the Department of Transport Equipment with the Todor Kableshkov University of Transport and the Bulgarian Academy of Sciences have made a detailed exanination on the existing Checkpoint systems in order to study the main principles of their operation and improve what has been achieved up to now. Moreover, to find a solution that will be appropriate to the Bulgarian railway infrastructure, the functional characteristics of Dutch, Austrian, German and Australian systems have been conprehensively analysed. It has turned out that the technical state of trains in motion can be controlled by such telematics devices. The vertical component of the dynamic force caused by the movement kinematics is the most important parameter under examination. There are two key concepts to construct such diagnostic devices: onboard or infrastructure positioned.

However, the control points established in key sections of railway network have important advantages compared to the onbord positioning in trains, e.g. stable operation, lower cost, easy and costly maintenance, universal application. For the reasons mentioned above, it is necessary to develop the potential of sensors installed in track superstructure elements,which in their structural unity form a completed measuring unit. It is a fundamental component in the concept proposal of a CheckpointBG system coupled with communication links.

2. Advanced international experience

The reform of the European Union's state railways (Directive 91/440/EC) has led to the opening up of the railway infrastructure for more and more train operators. Infrastructure managers now feel the urgent need for automated monitoring of the railway vehicles running over their tracks, often with high axle loads and at high speeds. Such a monitoring system enables them to judge whether or not the loads on their tracks caused by train operations correspond to the fundamental standards [16]. Subjecting the infrastructure to excessive loads results in extraordinary wear and tear on the track, which increases the money the infrastructure managers are forced to spend to rectify the situation. In addition, a monitoring system ought to satisfy all of the following:

- It ought not to interfere with the normal operation in any way, such as needing to have trains slow down when running over it;
- Whenever any of its limit values are exceeded, it ought to be able to issue warnings concerning specific vehicles;
- Ideally, it ought to be easy to set up, so that it can be moved between different track locations;
- It ought to be able to differentiate between clients, so that all customers can have access to the network without discrimination; it ought to be able to pass on the data captured selectively to the infrastructure manager and the various train operating companies.

According to the data from scientific publications describing the operation of systems Gothca, Lasca & Mattild, Argos, etc., the rail deformation accompanying the passage of the wheel is used as a source to get the necessary information about the size of load transported. Different manufacturers have embedded optical-fibre or laser sensors on the track and in some cases equip entire track units with strain gauges. Another feature of theirs is the operating speed range of up to 350 km/h, which is untypical for train traffic with difficult topographic conditions in the Balkan Peninsula. The environment temperature, which is declared to guarantee detection accuracy, covers the range from -30 to 50°C.

All Checkpoint devices in Western Europe hold minimal degree of moisture and dust protection IP65 but not all of them combine detection of overheating the braking system friction surfaces with violation of the boundary load on a wheel or axle [6, 13]. Only Argos systems offer monitoring on the train kinematic gauge and a mobile diagnostic laboratory with independent power supply occurs in systems Gotcha and Laska & Mattild. Parameters (operating functions) involved in the above-mentioned monitoring systems are:

- Parameter 1 - Origin
- Parameter 2 - Year
- Parameter 3 - Working speed
- Parameter 4 - Sensors / number, type
- Parameter 5 - Mounted railway type
- Parameter 6 - Measured length
- Parameter 7 - Measured number of axles
- Parameter 8 - Minimal distance between axles
- Parameter 9 - Wheels diameter
- Parameter 10 - Temperature of working environment
- Parameter 11 - Accuracy of load measurement
- Parameter 12 - Accuracy of speed measurement
- Parameter 13 - Identification system
- Parameter 14 - Time to make the report
- Parameter 15 - Type of report
- Parameter 16 - Type of connection
- Parameter 17 - Power supply
- Parameter 18 - Ingress protection marking / IPCode

These parameters are investigated in each monitoring system and shown in Tables 1 through 5.

Gotcha® is an open wayside monitoring platform to measure the quality of various aspects of trains [2]. The most common modules used are Wheel Defect Detection to monitor the quality of the wheels and the Weighing in Motion to determine the load of a passing vehicle. A variety of sensor types can be added to the platform to determine the state of different aspects of trains.

The sensors used in LASCA® Mattild are based on the principle of detecting the magnitude of the deflection of a laser beam by the deformation of the loaded rail [3]. The sensor is a highly sensitive yet robust component of its own design. It works similarly to a shift resistor and the laser beam acts as the center tap on rheostat. He works absolutely linear and is highly dynamic in all frequency ranges without interference from the outside. The raw data generated can be further processed directly in the software without filtering. The measuring system itself does not absorb any force and is therefore not overloaded. It measures the directional deformation of the rail (bending line) = proportional to the Q-forces. There is no interference of the measurement by wave-flow or compressive forces running in the longitudinal direction, and no interference of the measurement by temperature differences, weather, dust, or other external influences.

Table 1.
GOTCHA®

Parameter	
1- Origin	Holland
2 - Year	2000
3 - Working speed	15 ÷ 350 km/h
4 - Sensors /number,type/	8 ÷ 12
5 - Mounted railway type	UIC54;UIC60; BV50
6 - Measured length	1600 m
7 - Measured number of axles	500
8 - Minimal distance between axles	0.7 m ÷ 24 m
9 - Wheels diameter	330 mm ÷ 1600 mm
10 - Temperature in the working environment	from -40 ÷ 50°C
11 - Accuracy of load measurement	3%(30-70 km/h)
12 - Accuracy of speed measurement	no data
13 - Identification system	AVI Tags
14 - Time to make the report	1 min
15 - Type of report	XML/TCP(IP)
16 - Type of connection	GSM(R); GPRS; Ethernet
17 - Power supply	230 V AC; 24(110) V DC
18 - Ingress protection marking/ IP Code	IP65

Quality assurance in production and in maintenance are the most important prerequisites for achieving optimum performance. The decisive factors for rail safety are vertical wheel forces and wheel set loads, as well as optimum load distribution. The flexible, modular structure of MULTIRAIL® Wheel Load's hardware and software precisely assesses these values regarding locomotive and rail car bogies. This saves time and costs while at the same time also ensures quality.

With MULTIRAIL® Wheel Load System it is offered a totally new system for the determination of wheel loads of rail vehicles [4]. The measurement system is especially designed for the workshops dedicated to the construction and repair of rail vehicles. The precise and modular MULTIRAIL measuring technology provides wheel and axle loads as well as the load distributions of traction and secondary vehicles with a high degree of accuracy according to the relevant standards (EBA, DIN, TRF). In addition, the wheel loads of passenger cars and freight wagons can be easily determined.

Basic functions of MULTIRAIL® Wheel Load system are:

- Monitoring of wheel and axle loads
- Determination of relative wheel load differences
- Monitoring of wagon weights and wagon centre of gravity
- Printout and storage of weigh data

Table 2.
LASCA® Mattild

Parameter	
1- Origin	Germany
2 - Year	2001
3 - Working speed	1 ÷ 350 km/h
4 - Sensors /number,type/	12
5 - Mounted railway type	all types
6 - Measured length	no data
7 - Measured number of axles	no data
8 - Minimal distance between axles	no data
9 - Wheels diameter	no data
10 - Temperature in the working environment	from -45 ÷ 50°C
11 - Accuracy of load measurement	2% ÷ 3% (min 100N)
12 - Accuracy of speed measurement	no data
13 - Identification system	ZLV Bus
14 - Time to make the report	2 min
15 - Type of report	FTP; XML; GSV; SAP/ISI
16 - Type of connection	Intranet; Internet; IDSN
17 - Power supply	230 V AC 50Hz
18 - Ingress protection marking/ IP Code	no data

Argos® Systems makes it possible to expand requirements for accuracy and functional scope at any time during the usage period. All basic elements are already prepared for future upgrades [5]. This makes it possible to expand train monitoring equipment in small investment steps, beginning with a basic installation.

Argos® Instant is able to measure dynamic forces exerted by the vehicle on the superstructure. This can be used in turn to determine train and vehicle weights. Dynamic forces provide information about wheel irregularities and easy installation with clamp-on sensors makes these modules suitable for temporary applications.

Argos® WIM (dynamic weight) can be used to acquire the load status of vehicles at normal line speed with the greatest possible accuracy. This makes it possible for example to compare a bill of lading with the actual weight during operation. Another advantage is that technical limit values can be monitored efficiently and precisely.

Table 3.
MULTIRAIL® Wheel Load

Parameter	
1- Origin	Germany
2 - Year	2001
3 - Working speed	10 ÷ 40 km/h
4 - Sensors /number,type/	8 ÷ 14
5 - Mounted railway type	all types
6 - Measured length	no data
7 - Measured number of axles	no data
8 - Minimal distance between axles	no data
9 - Wheels diameter	no data
10 - Temperature in the working environment	from -50 ÷ 70°C
11 - Accuracy of load measurement	0.50 %
12 - Accuracy of speed measurement	no data
13 - Identification system	RFID
14 - Time to make the report	no data
15 - Type of report	HTML; text
16 - Type of connection	no data
17 - Power supply	no data
18 - Ingress protection marking/ IP Code	IP68

Argos® OOR (out-of-roundness) measures the deviation from an ideally round wheel with a delta R resolution better than 0 01mm, repeatability 0.05mm as a trend function and 0.1 mm as an individual measurement. The measurements can be performed from a speed of 40km/h and covers the entire circumference of the wheel in the area where the wheels come in contact with the track. The measurement system is designed so that a least two wheel blanks (two overruns) are measured for each wheel. The progression of delta R over the circumference of the wheel is used by the system to derive and quantify types of wheel shape irregularities. The measurement results of a wheel can be generated both numerically and graphically for a speci-c case. In practical applications, global results are typically used for the individual measurements of each wheel.

3. Key features of the proposed system named CHECKPOINTBG

What are the main functions of the Bulgarian system offered by the team? First, it is necessary to produce a protocol addressed to a particular vehicle of the train for each measurement. For this purpose, it is necessary to recognize the individual units of train according to the registration number, which can be accomplished in two ways:

- Using radio frequency sensors;
- Through intelligent optical sensors.

Along with identification of vehicles, it is necessary to carry out measurement determining the interaction of the rail vehicle with the track, which is an indirect diagnostic parameter showing the technical condition of undercarriage, the size and distribution of load on the wheels [9]. This includes detection of damages on the wheel surface, which affects the picture of the interaction. Another function offered by the authors is to trace temperature changes on friction surfaces of the braking system, bandages profile and axle-box assemblies. The entire system would lose its meaning without building an effective telecommunication connection between subsystems and points. The schematic diagram of a system is shown in Fig. 1.

RFID is implemented as RFID-tags containing information about the registration number and series wagon are fixed in a specific part of the vehicle frame. They do not need power supply and receive charging necessary for their operation by inductive contactless way from RFID-reader located near the track. Thus the numbers of all wagons passed are recorded, which besides identifying reveals possibility to control the integrity of the train set [7]. The disadvantage of this system is the mandatory equipment of all vehicles with RFID-tags.

The Recognition System based on intelligent optical sensors operates through cameras mounted at certain height that scan the numbers of wagons and after subsequent image processing by the software compare the to numbers from the database [15].

Table 4.
Argos® Systems

Parameter	
1- Origin	Austria
2 - Year	2004
3 - Working speed	5 ÷ 300 km/h
4 - Sensors /number,type/	14
5 - Mounted railway type	all types
6 - Measured length	Min 700mm
7 - Measured number of axles	32 pro vehicle
8 - Minimal distance between axles	no data
9 - Wheels diameter	300 ÷ 2000 mm
10 - Temperature in the working environment	from -50 ÷ 75°C
11 - Accuracy of load measurement	1÷ 2 %
12 - Accuracy of speed measurement	0.5 km/h
13 - Identification system	RFID
14 - Time to make the report	5 sec
15 - Type of report	XML
16 - Type of connection	LAN direct GSM/UMTS
17 - Power supply	9÷40V AC; 230V AC
18 - Ingress protection marking/ IP Code	IP67

The measurement of load in creep (contact patch) for each wheel of railway vehicles is a function of primary importance for the proposed system. Worldwide it is done by monitoring on the rail mini deformation and is a result of the total static-dynamic force impact. The static load transmitted to the superstructure elements can be measured and is under the condition of rest. But since the dynamic component is a variable of hidden nature and it highly depends on the kinematics of movement and appearance of faults in the tread, it is a subject of great interest in the diagnosis of railway vehicles motion. Sometimes its size exceeds the part of static load distributed on individual wheels several times. Worldwide it is determined by optical fibre, laser or Strain sensors. The authors' idea is the use of accelerometer sensors measuring (Fig. 2), the magnitude of acceleration acquired by the rail under the effect of shock cyclical loads to determine its value.

Another parameter, which is very important for operational safety and has to be controlled, is the temperature in typical areas of the elements of braking and bearing units. The use of thermal cameras to record heating lies in the basis of constructing these subsystems.

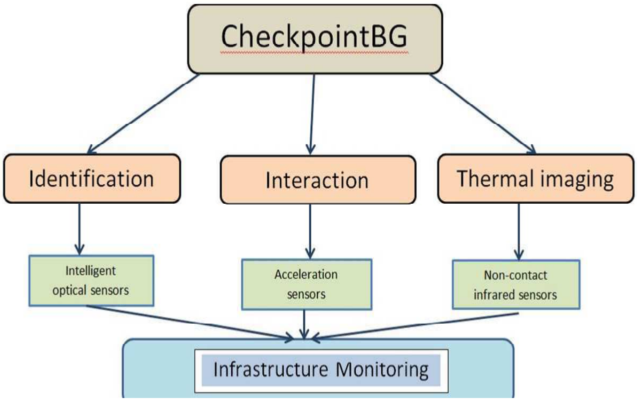

Fig. 1. The schematic diagram of a CheckpointBG system

Fig. 2. Accelerometer sensors measuring system

4. Comprehensive structure for information exchange and monitoring

The data from the train passing along the diagnostic unit are transmitted to the local computer, which is equipped with special software to process information and form a completed report on the actual railway vehicle state. The reports of individual diagnostic stations in different points of the rail network are sent to a central server where to be viewed, analyzed and stored. The access can be provided for the infrastructure manager and partialy open for third parties directly involved in rail transportation of people and goods.

5. Conclusions and future application of the pilot project results

The team of authors have ambition and experience required for successful implementation of the proposed model. A number of devices to monitor and control the state of undercarriage elements of railway vehicles have been implemented by the order of corporate structures such as the Bulgarian State Railways (BDZ) and the freight wagon factory Transvagon AD. The device for measuring the static wheel load of Siemens trainsets in the maintenance workshop in the city of Varna was recognized as an effectively functioning unit by the German colleagues and warded Certificate of Quality by an authorized representative of the Deutsche Bahn AG.

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Additional information

Selected issues related to this paper are planned to be presented at the 22nd Winter International Scientific Conference on Achievements in Mechanical and Materials Engineering Winter-AMME'2015 in the framework of the Bidisciplinary Occasional Scientific Session BOSS'2015 celebrating the 10th anniversary of the foundation of the Association of Computational Materials Science and Surface Engineering and the World Academy of Materials and Manufacturing Engineering and of the foundation of the Worldwide Journal of Achievements in Materials and Manufacturing Engineering.

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