S. VESKOVIĆ, Ž. ĐORĐEVIĆ, G. STOJIĆ, J. TEPIĆ, I. TANACKOV

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NECESSITY AND EFFECTS OF DYNAMIC SYSTEMS FOR RAILWAY WHEEL DEFECT DETECTION

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Preliminary Note – Prethodno priopćenje

State of railway vehicles highly influences transport safety due to vehicle derailments and in the same time worsens the quality of freight and passenger transportation. One of important elements that influence the state of railway vehicles is the wheel state. Wheel defects are common in railway transport. Therefore, timely defect detection is very important. This paper presents ways and effects of timely detection of wheel defects.

Key words: railway wheel, defects, diagnostics, dynamic monitoring.

Potreba i efekti dinamičkih sustava za detekciju defekata točkova željezničkih vozila. Stanje željezničkih vozila bitno utječe na sigurnost prometa zbog rizika iskliznuća i istovremeno smanjuje kvalitet prevoza robe i putnika. Jedan od bitnijih čimbenika koji utječu na stanje željezničkih vozila jeste stanje točkova. Defekti točkova su česta pojava u željezničkom prometu. Iz tog razloga, veoma bitno je pravovremeno otkrivanje defekata. U ovom radu su prezentirani načini i učinci pravovremenog detektiranja defekata točkova.

Ključne riječi: željeznički točak, defekti, dijagnostika, dinamički monitoring

INTRODUCTION

An extraordinary event in railway operations implies an event which impedes or makes service impossible, endangers human lives and destroys railway property and goods in transportation. Analyses show that about 60 % of extraordinary events in railways are caused by the technical malfunction and about 40 % are the consequence of human failures in operations or maintenance.

For equipment for contactless detection of overheating, flat spots, uneven loading or loading out-of-gauge the most interesting are derailments in the process of shunting. This is the biggest cause of accidents on Serbian Railways (SR) (77 % ÷ 100 % in the last two years), and a large number of operating accidents (about 17 %, but in the last two years over 20 %).

Higher degree of automation on railways is achieved through process of modernization. The current world trend is the application of modern control systems for a dynamic monitoring of vehicles [1, 2].

In addition to brake systems wheel sets are important from the point of reliability and safety of railway vehicles. Risk of derailments exists, threatened by poor technical condition of the wheels. This is why early detection of wheel defects and the implementation of systems for their detection are multiple profitable for infrastructure managers and railway operators.

S. Vesković, Ž. Đorđević, University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia
G. Stojić, J. Tepić, I. Tanackov, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

WHEEL DEFECTS

The nature of defects can be different: mechanical wear, defects in wheel material and non-homogeneous material, defects caused by heat stresses and overheating.

All defects that may happen on the surface of the wheel rolling circle are divided into seven groups (Figure 1).

The wear of wheels and rails results from a complex dynamic relationship within the movement of rail cars at the track with wheelspin. Analysis of wear of tracks and wheels are essential for safety and economics. The most important influences on the wear rate are usually classified into several groups [3]: wheel and rail materials, geometry of the wheel-rail contact, variations in production and assembly, the conditions of exploitation,

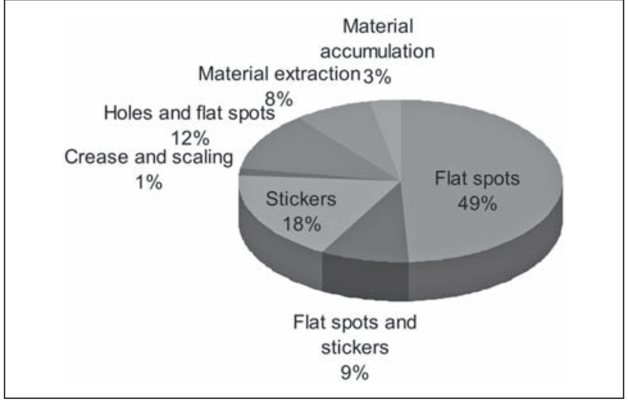

Figure 1 Defects on the surface of the wheel rolling circle

constructional features of the vehicle that affect its dynamics and motion track geometry.

The hardness of the material point of the rails, determine the speed of their wear. Wear is less when the material is harder than the material point rails. Recommended point is that the material has a hardness of up to 10 % higher. The wheel wear process significantly affects the heat treatment process applied. On the basis of experimental tests it has been proofed that for same hardness it can be got in different wear [4]. Normal hardening annealing gives a very negative resistance, while isothermic hardening during the pearlite phase gives better results.

European standard for making of wheel steels defined as follows steels: ER6, ER7, ER8 and ER9. Hardness Brinell, to a depth of 35mm below the surface is given in Table 1.

Table 1 **Hardness on the wheel edge by Brinell**

Steel mark	The minimum value for categories	
	K1 (>200 km/h)	K2 (<200 km/h)
ER6	-	225
ER7	245	235
ER8	245	245
ER9	-	255

Studies have shown that increasing the surface hardness of the rolling wheel on thermal treatment of HB 450, and wreath on HB 600 ÷ 800, may 1,5 ÷ 3 times reduce wear of wheels and rails [4].

During braking process, the brake pad in contact with surface of rolling wheels, the vehicle kinetic energy of is converted into heat and in very high percentage transferred to the wheel. Consequently temperature rises and can reach values that cause the limit excees of elasticity of materials, plastic deformation and residual stresses after cooling. These residual stresses can be large enough to cause the initial point cracks at the edge of the wheel (broken) and even breaking point with major consequences for safety.

The main indicator of the thermal load point is the colour transition between the rim and wheel body or the traces of oxidation on the edge of the wheel. If the brake pads are outside of the wheel rolling surface, then the high thermal stresses occur, especially in the outer part of the surface which gives rise to excessive residual stresses and wheels braking. Typical examples of wheels braking are shown in Figure 2.

Figure 2 Typical examples of wheels braking [5]

The break points may be affected by defective construction vehicles and low quality materials in manufacture.

Occurrence of defects is caused by the heating of the wheels due to braking. Heating rolling surface leads to plastic deformations, and thus to increased wear due to friction.

Another type of defects are defects of thermal-mechanical nature. These defects are characterized by creation of rings around the wheel edges, especially in the case of brakes made of composite materials. The reason of these defects are unequal working conditions on surface layers of metal wheels and brakes in the contact zone and the penetration of abrasive particles and dust on the metal surface along the edge of brake. Local resistance point ("flat spot") are caused by wheels blocking as results of plastic deformation caused by heating of the contact surface.

Thermo-mechanical defect is creation of labels and annealing sites ("white spots") on the rolling surface. Both defects are due to the combined effects of wheel heating. Above mention layers have high hardness (up to 900 HB) and features of high residual voltage due to which form micro cracks. Stickers can also be torn of the wheel which leads to straining of axel, vehicle and rail.

White spots are caused by sudden cooling of overheated to a temperature higher than the critical for structural changes in the surface layers of metal wheels. Low temperature and high humidity contribute to the appearance of white spots.

Transverse cracks on the surface of the wheel are prevalent form of defects, resulting of alternating heating during braking and cooling.

Unusual and undesirable defect is tearing of metal wheels under the influence of external and internal forces. It precedes the disorder homogeneity of the material ("pulling out of material"). This defect contributes to the martensitic structure of the surface layers of metal which is characterized by high hardness and breakability.

The main reason for the formation of flat spots is improper braking (air brake overload devices, tightened the handbrake and the wrong braking lever). In the case of brake inserts of composite materials and higher braking level starts thermal overheating, and thus the appearance of defects on the surface of the wheel rolling surface [3].

DIAGNOSIS OF DEFECTS WHEELS

Stationary systems used for diagnostic and monitoring on open line diagnose the mechanical condition indirectly (temperature and noise measuring) and directly (measuring the acceleration of the mechanical part in the movement).

Measuring stations provide continuous monitoring of vehicle status and parameters of superstructure loads. Measuring equipment (installed on the line) and the measurement process does not interfere with the normal conduct of transport.

Example of installation check point for railway wheel defect detection with dynamic weighing is shown on Figure 3 [6]. Check point measure all axle loads and vertical interactions between rails and wheels on vehicles in movement at a speed of 120 km/h.

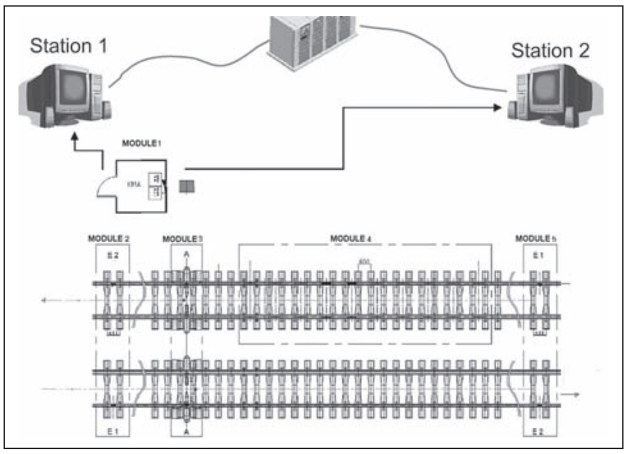

Figure 3 Sheme of stationary installation

Generally, the trains are registered in both travelling directions; weighbridge axles' temperature is measured contact less on the left and on the right side. Simultaneously, the wheel center and brake disks temperature is also measured. Every body that has a temperature above absolute zero emits electromagnetic radiation proportionally to its temperature. The wavelength of that radiation is within the range 0,7 ÷ 1000 μm. The range of interest for technical measurements is 0,7 μm to 14 μm [6].

The most important characteristic of the device for detection of overheated axle bearing (HOA) is double checking of axle bearing' pair of wheels. Sensor device uses gauges which follow rail deflection caused by the wheel seating force. Sensors are put onto the rail, between sleepers.

A computer loads measu-rement data when the train passes through measurement point and calculates axle loads of every wheel and the size of flat places. Sensor device is mounted on the rail side, along neutral line (Figure 4). Gauges are welded onto the rail.

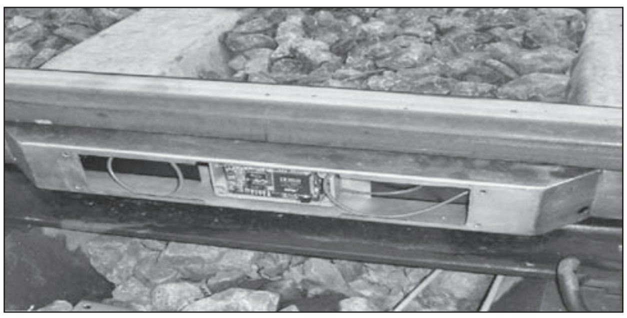

Figure 4 Measurement module in a box

In a case of any irregularity detected on trains passing over the installation, pictogram alarms will be shown on each monitor connected to the stationary system network (Figure 5 a, b, c and d).

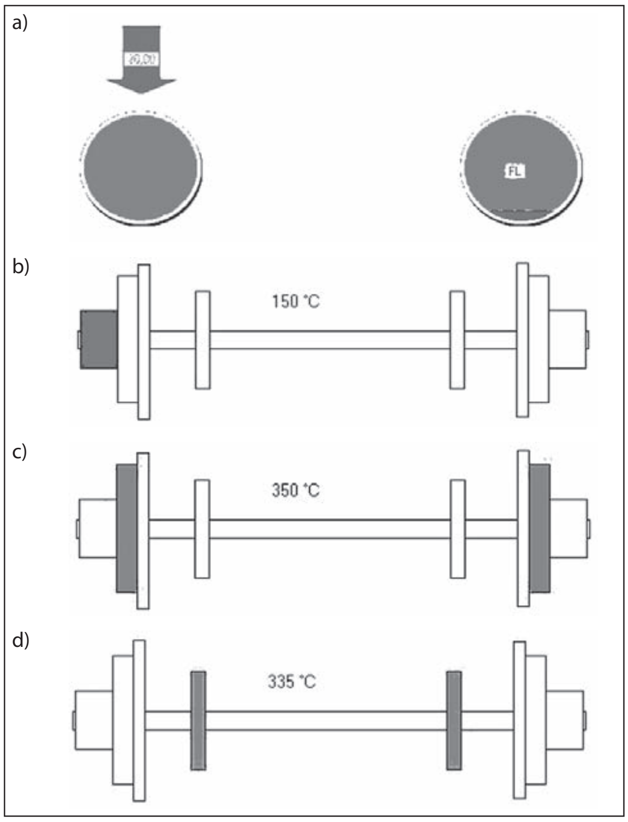

Figure 5 Irregularity detection: a) Overloaded wheelset and wheel flat spot, b) Overheated bearing detection, c) Irregular wheel temperature d) Irregular brake disc temperature

MODEL FOR EFFECTIVENESS EVALUATION OF EQUIPMENT INVESTMENT

The specific view in the accident data base is given by the aspect whether it is possible to recognize one fault state by some wayside monitoring system. Risk is always defined as a product of probability and severity. The European standard [7] offers the possibility to deal with different risks by using a risk matrix [8]. For operational application the qualitative descriptions of probability and severity are quantified (Table 2). The calibrated matrix covers the range of operational scope. The protection goal for wayside train monitoring at SR is set up to 500 000 € per year. Finally, the protection goal divides the matrix into two areas: one below the protection target and one above the protection target where there is a serious demand to set preventive measures to reduce risk to the infrastructure manager caused by car related fault states which may destroy the infrastructure.

The estimate of installations application is carried out after taking into consideration all costs and benefits by standard dynamic ratability methods.

Results for the investment estimate are:

- Internal rate of return (IRR) = 11,99 %,
- Net present value (NPV) = 603 719 €.

The Internal rate of return, which is inside the profitable zone, leads to the conclusion that the investment is profitable from an economic point of view. The Internal rate of return would be significantly higher if indirect costs could be taken into consideration.

The Sensitivity Analysis has been carried out after estimates of all relevant financial effects which can come about from this investment. The relationship between input parameters and the Project rate of return has been analysed. The Sensitivity Analysis has been carried out using the following assumptions – IRR:

- Basic case = 11,99 %
- Increase of investment by 20 % = 9,64 %
- Decrease of investment by 20 % = 15,32 %
- Increase of savings 20 % = 14,78 %
- Reduction of savings 20 % = 9,26 %.

Table 2 **Calibrated risk matrix in Mio.€ per year [8]**

A (Weekly)	0,24	2,4	24,0	240,0
B (Monthly)	0,06	0,6	6,0	60,0
C (Once a quarter)	0,02	0,2	2,0	20,0
D (Yearly)	0,005	0,05	0,5	5,0
E (Once in ten years)	0,0005	0,005	0,05	0,5
F (Once in one hundred years)	0,00005	0,0005	0,005	0,05
	IV (Insignificant - 5 000 €)	III (Marginal - 50 000 €)	II (Critical - 500 000 €)	I (Catastrophic - 5 000 000 €)

CONCLUSION

Unlike Western European and Central European railways on Serbian Railways detections of overheating, flat spots, uneven loading or loading out-of-gauge are performed only when the train stops at the station. In the world already exist more sophisticated methods that can detect defects during the movement of trains.

With the aim of failure detection it seems to be important to install a wayside network of train monitoring devices which are capable of non-contact and dynamically detection, processing and reporting of appropriate signals (at a distance and with the required accuracy) in the case of overheating, flat spots, uneven loading.

As it is clearly shown in the project sensitivity analysis, the project is highly resiliant to all variations of input parameters and also to expected divergences. The facts indicate investment return and necessity of immediate project realization which should significantly reduce costs for both infrastructure and vehicle maintenance.

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Note: The responsible translator for English language is I. Belošević, University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia