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## USING ACCELERATION SIGNALS RECORDED ON A RAILWAY VEHICLE WHEELSETS FOR RAIL TRACK CONDITION MONITORING

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### ABSTRACT

The subject matter of the paper is the partial analysis of the results of acceleration signals from the prototype of *Rail Vehicle's and Rail Track Monitoring System* exploitation. The prototype of the system measures and records acceleration signals on some elements of electric multiple unit. The chosen analysis are connected to track condition, however connection to vehicle condition are also mentioned. Appropriate conclusions and future research proposal are given.

**KEYWORDS** : *diagnostic parameters, monitoring system, signal analysis, condition monitoring.*

### INTRODUCTION

A railway track is an important factor in providing a good transportation system, therefore its maintenance and renewal take a lot of finances. The cost of maintenance, renewal and safety (which intensively relates to both before) of railway operation depend, among other things, on the quality of the rail track. Therefore, the necessity to monitor the condition of railway track, while rail vehicle is moving on it, appears to be extremely important. Inspection and maintenance of railway networks – is without any doubts – an important, complex and expensive task. Generally some special measurement vehicles or devices are used to record the geometrical properties and parameters of railway network lines within required time intervals. In some research quality of railway track is evaluated considering only a few parameters. Although safety and comfort of wheel-rail systems depend on the dynamical behaviour, in case of mentioned inspection, vehicles are not equipped to measure dynamic properties. That was one of many reason to start research on *Rail Vehicle's and Rail Track Monitoring System*. This is monitoring system of the state of rail vehicle and railway track elements, therefore its main aim is to monitor the condition of rail vehicle and railway track. Using, exposed in the topic of the paper, acceleration signals recorded on a railway vehicle wheelsets for railway track condition monitoring makes consideration of the dynamic behaviour possible. The presented system would make it cheaper and easier than in case of inspection vehicles (devices). That is due to the fact the system would be added to rail vehicles, which are in normal exploitation on the railway network. The subject matter of the paper is the analysis of the results of acceleration signals recording and measurement obtained from the prototype of *Rail Vehicle's and Rail Track Monitoring System*. The monitoring system is being researched and implemented under *MONIT – Monitoring of Technical State of Construction and Evaluation of its Lifespan Project*. The prototype of mentioned system was installed on electric multiple unit (EMU) *ED-74* produced by *PESA Bydgoszcz SA*. and lent for prototype instalment by *PKP Intercity SA*.

The prototype of the system records and measures acceleration signals on some elements of *EMU*. To mention these elements such as bogie frames, wheels and railway vehicle bodies are places of accelerometers instalment. Acceleration sensors locations are given in the paper. In case

of track condition monitoring the accelerometers installed on axel boxes are the most important due to the fact of recording acceleration signals *e.g.* as the aim of track quality indicator computation.

*ED-74 EMU* with the prototype of the system passed through a number of railway lines of *Polish National Railways* network within Poland. However the analyses were prepared on the basis of rail vehicle rides on example section of the *Polish National Railways* network. Before supervised operation of the prototype, simulation results were evaluated for series of rail vehicle passages and referred to other results. In particular, the paper considers the track quality indicator, but in view of objectives of the project there is no way not to mention the correspondence with the rest of the diagnostic parameters under consideration for the opportunity to monitor and diagnose the rail vehicle-track configuration, previously developed and supplemented during the research in experimental supervised rides of rail vehicle with the prototype installed. The values of diagnostic parameters, when compared with the limit values, allow to monitor the typical dynamic behaviours of rail vehicle and track condition and temperature of rail vehicle wheelsets bearings, and to determine condition of a rail vehicle construction. As it is in case of condition of track. The track quality indicator allows to measure condition of track. One of purpose of the analysis is to determine the usefulness of the topic diagnostic parameters and to identify the direction of further research connected to monitoring a track condition.

## 1 LITERATURE REVIEW

At first, it is hard not to mention previous research of the system on the view point of rail vehicle condition. Research on condition of suspension elements (springs and dampers), determining vehicle dynamic behaviour and in consequence affecting derailment safety directly, were incorporated as research on statistical measures of vibroacoustic signals. The research and studies are given in dozens of papers *e.g.*: [1-4]. In particular, the group of works on selection of diagnostic indicators should be distinguished. This group includes: [4-8].

From the point of view on track condition, research – which are focused mainly on the development and usage of track quality indicator – are given, *inter alia*, in papers: [9-11]. In these outcomes researches, some evaluation analysis of the track quality on the basis of previous acceleration measurements were carried out and discussed. During the period, when *MONIT* research project was under examination, that was not the only solution considered track condition in terms of the recognized technical state of the art. Some other realizations, beyond the *MONIT* project, are given below.

Monitoring the track condition, its irregularity and transverse destabilization are currently problems discussed in the literature. Both in literature and in the midst of practical technical solutions stationary and non-stationary devices for track condition measurement are distinguished.

Among the stationary equipment there are *e.g.* Slope Indicator Track Monitoring System [12], SenTrack™ Track Monitoring System [13], RST Instruments Track Monitoring System [14]. They are characterized by some functional limitations. Slope Indicator Track Monitoring System [12] is the system, which monitors railroad tracks by monitoring settlement and twist only. “*The systems are installed when nearby construction activities, such as tunnelling or excavation, may affect the safety of the tracks. The systems are also installed on tracks that pass through areas endangered by landslides or washouts. Settlement of the track is monitored by linked track-settlement sensors that are mounted directly on the ties (sleepers). With continuous track, the track settlement sensors are anchored in the ballast instead. Twist in the track is monitored by track twist sensors mounted on the long-axis of the ties*” – according to [12]. Thus, this system does not necessarily prepared for similar purposes as discussed in this paper.

In contrast, among the non-stationary devices BRSSOS Track Monitoring [15] and T & T Sistemi Railway Track Quality System [16] can be distinguished. These devices are designed to monitor the track in case of operation and maintenance of rail routes.

As it might be obvious, such systems must be known especially in case of track where high-speed trains run. There are, to mention only some of many: a practical system called HISTIM

(High-Speed Track Inspection Machine) that was installed as an additional method of track recording and has been in operation on track geometry cars on Shinkansen lines in Japan [17] and other systems: TRASC (TRAck State Confirming machine, [18]), TRIPS (TRAck Information Processing System, [19]), RARO (RAil ROughness continuous measuring machine,[17]).

Some other research consider ground penetrating radar. These are *e.g.* [20] or [21]. However, these are directly connected to track settlement rather than dynamics changes in the rail vehicle-track system that are expressed in this paper.

In the paper [22] a novel approach to evaluate the quality of railway tracks based on wheel-rail dynamics discussed. Authors analyse wheelset dynamics of underground trains by Karhunen-Loève transformation to extract the principal dynamics from measurement data.

From the literature review the main conclusion comes. There seems to be lack of the system installed on the rail vehicles normally used for people or freight transportation, which could lack of track condition measurement. There are many special and specialized equipment and devices to do such measurement.

## 2 PHYSICAL MODEL IN THE RESEARCH

The physical model of *Rail Vehicle's and Rail Track Monitoring System* was described from different points of view in many papers *e.g.* [1-11]. It is worth to mention some information here, specific to the problem.

The functional scheme of the system structure is given in fig. 1a. Signals from the sensors (accelerometers) are transmitted by wire connection to the local data acquisition unit (LJAD) mounted on the vehicle. Then signals are transmitted (again *via* wire connection) to a central data acquisition unit (CJAD), where data (signals) are subjected to preliminary analysis. Subsequently, the signals from CJAD are sent wirelessly to a system server, where they are analysed and collected.

As the result of analysis the appropriate diagnostic indicators characterizing the condition of vehicle and track are calculated. And then qualitative information about their condition are generated. This information is up to date sent to the relevant departments supervising the movement of vehicle and authorities responsible for technical and operational condition of vehicle and track. The location of the vehicle is described by geographical coordinates and is shown on the electronic map of Poland, therefore information about the vehicle and the condition of the track are uniquely identified with the place in the country area. Based on this information, it is possible to make decisions about necessary repairs, renovations or replacement of vehicle or track.

Acceleration signals are recorded by piezoelectric accelerometers. The generalization of the number of sensors and their placement can be configured in any way. However, for diagnostic purposes and the approval testing, it must comply with the requirements of Polish norm: PN EN 14363 (2007). During research of the system, the following sections of the rail vehicle were taken into consideration in case of acceleration sensors position to be installed:

- wheelset bearing (axle boxes),
- bogie frame, over the wheel,
- vehicle body, over the centre of the bogie frame.

To be specific, the proposed localisation of chosen measurement points can be seen in fig. 2.

The monitoring system is suitable for detecting faults in primary and secondary suspension, alike, as it was mentioned before, detecting problems connected to track. Primary suspension are elements that connect wheelsets to bogie frames. Secondary suspension are elements that connect bogies to a vehicle's body. For the primary suspension condition assessment, acceleration signals registered on a bogie frame are used (fig. 2 – marked as 1 and 2). Sensors mounted on a body, above bogie centre (fig. 2 – marked as 3) are used in order to monitor secondary suspension condition. As far as the track condition is concerned, acceleration signals are registered by accelerometers located on wheelset bearings (fig. 2 – marked as 4-5 on one side of construction and as 6-7 on other side of construction).

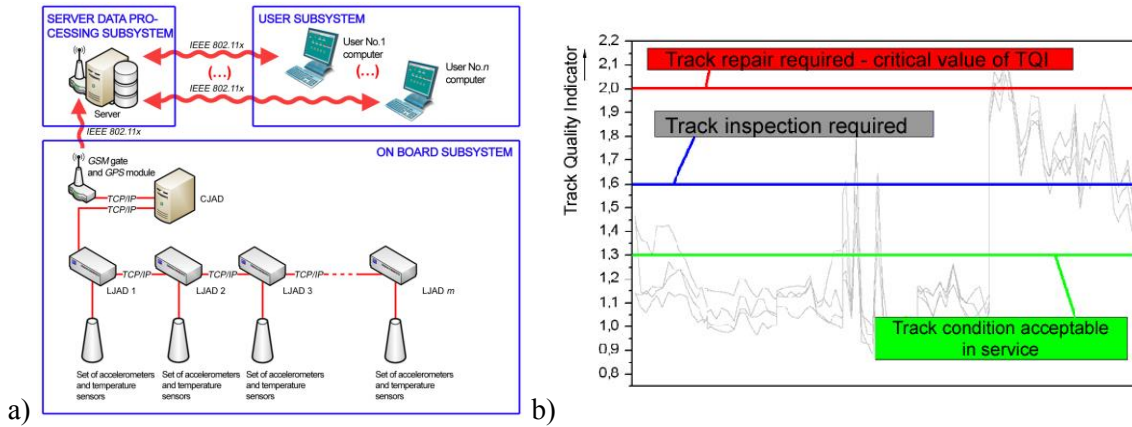


Figure 1: Scheme of Rail Vehicle's and Rail Track Monitoring System (a) and the boundaries track quality indicator values (b)  
 Source: for a): [4, p. 11], for b): [23, p. 18]

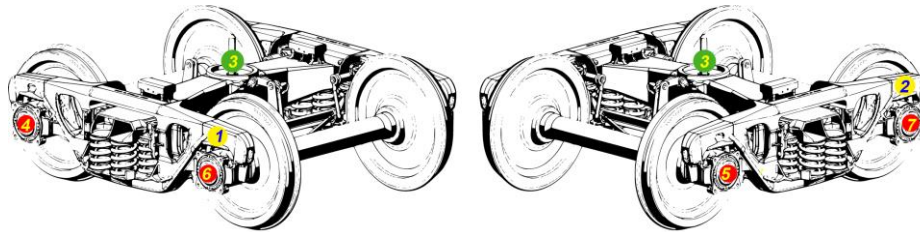


Figure 2: Localization of chosen measurement points  
 Source: based on <http://www.clipartfree.net/svg/17083-railway-truck-download.svg>

Track condition monitoring is performed by means of acceleration signals recorded on the axle boxes. The recorded data are submitted in order to compute a track quality indicator. A track quality indicator is described by formula (1).

$$W_t = c_t \cdot \left\{ \lim_{T \rightarrow \infty} \left[ \frac{1}{T} \int_0^T a^2(t) dt \right] \right\}^p \tag{1}$$

where:

- $W_t$  – track quality indicator,
- $c_t$  – constant value set on the basis of the numerical research,  $c_t = 1$ ,
- $T$  – time of data recording,
- $p$  – constant value set on the basis of the numerical research,  $p = 0.225$ ,
- $a(t)$  – vector of filtered acceleration signal, in function of time.

The threshold values gained in the previous research – presented e.g. in [23] – are given on the fig. 1b. These are: critical value of track quality indicator (the value is equal to 2.0; and means that track, which track quality indicator value is at least equal to 2.0, should be undergone repair), permissible value of track quality indicator (the value is equal to 1.6; and means that track, which track quality indicator value is at least equal to 1.6 and less than 2.0, should be subjected under inspection however the condition of track is quite acceptable).

### 3 CHOSEN RESULTS AND DISCUSSION

As the case study to be discussed in the paper, one day of rides of EMU (with system's prototype installed) were chosen. It is January 25<sup>th</sup>, 2012. This day, the EMU train (consisted of 5 bogies: A-E) was on the route from Warsaw to Posen. In the case of this ride no data related to A-bogie were recorded on the systems. Similarly, due to the fact of different configuration of accelerometers on

the E-boogie, it is not taken into consideration here. However data related to the rest of bogies (B, C, D) can be discussed. As it can be seen, in three charts in fig. 4, the highest values of track quality indicator was registered in case of data packet No 79. Let us describe then what was happening there, on the track, in case of the packet. The data packet No 79 was recorded in the system in the same moment of time (18:33'34'') from B-, C-, D-bogies in Sochaczew after EMU riding of 1 km long and data recording (every 0.2 m). The coordinates of the data packet No 79 recorded in the system was: N52° 12' 15.6941" E20° 13' 15.1667", which means it was about 100 m behind the railway crossing on Fabryczna Street (fig. 3). It is presented in fig. 3 and is signed as A symbol on the map. It must be expressed here that the values given on the charts (fig. 4) in case of the packet are values after, *inter alia*, re-sampling and statistical processing of all 1 km long data recording. The value decomposition on the length of 1 kilometre is shown in the separately graphs (fig. 5, 6). B and C symbols on the map (fig. 3) are expressing the places where a "sudden" increase of track quality indicator occurred. It was in the case of level crossing (B) and railroad switch or railway turnouts (C). This is especially "underlined" in case of B-bogie measurements – fig. 5. Part C on the map is shown in a larger scale, to allow occurring the presence of the railway turnouts in this location. In fig. 5, 6 places where level crossing and railway turnouts occur are as follow. First few metres concern the railroad switch or the railway turnouts and last dozen of metres (the highest peaks in fig. 5) concern the level crossing. It must be mentioned that in case of B-bogie values of track condition indicator are higher than in case of C- and D-bogie, as it can be noted in fig. 5, 6. One of the reason of such a situation is the fact that this measurement parameter might be sensitive to quality of vehicle and it was noted during operation of the vehicle that the B-bogie was of worst quality than the rest of bogies. As it can be seen both in case of fig. 5, 6 and after re-sampling and statistical processing in case of fig. 4 no value of track quality indicator exceeded the boundary value. The boundary value of track quality indicator was adopted on the basis of the previous considerations. It is the limit values of the quality of the track, providing a problem associated to track condition. And these all mean that there are no serious problems related to the track condition in 1 km long exposed in the exemplified case study of the research on the system. However the inspection of the track condition is suggested due to the fact that some values of track quality indicator (especially in area of level crossing) are higher than 1.6.

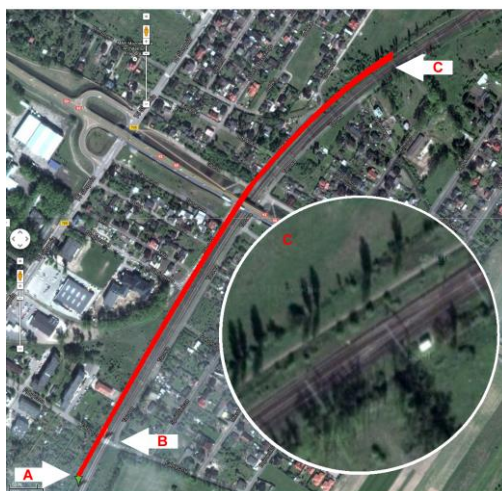


Figure 3: A part of Warsaw-Posen route  
Source: Kostrzewski M. based on Google maps

Differences between left (4TQI) and right (7TQI) side of railway given in fig. 4 might give some additional information about track irregularities. This is the matter worth of future analysing.

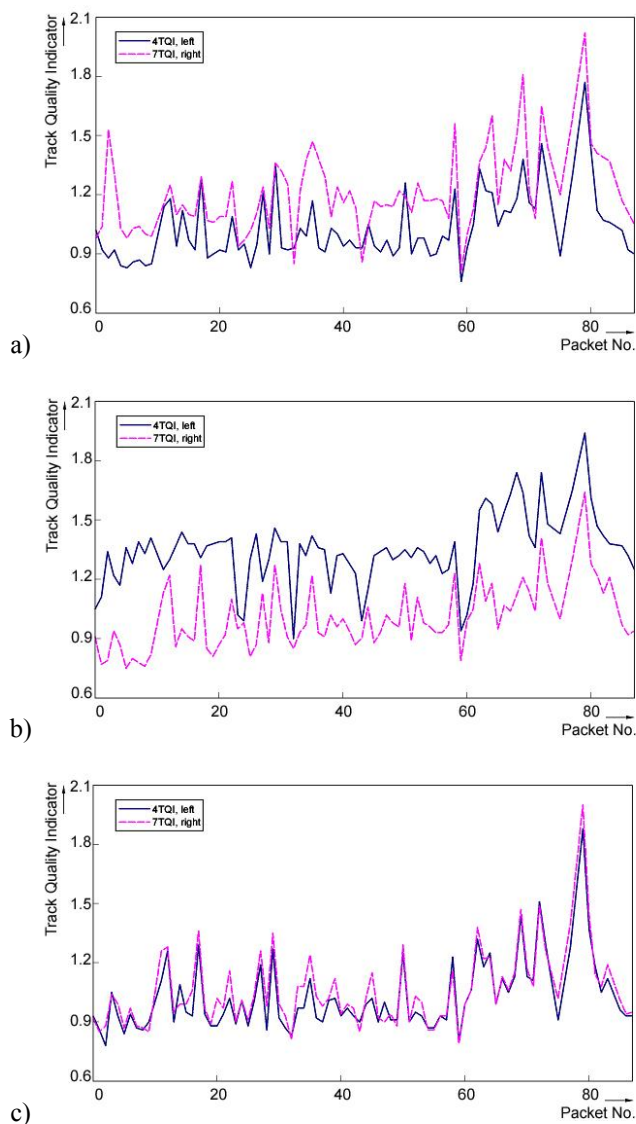


Figure 4: Track condition chart along Warsaw-Posen route on January 25<sup>th</sup>, 2012 in the case of a) B-bogie, b) C-bogie, c) D-bogie – comparing the values of track quality indicator obtained on the right and the left rails

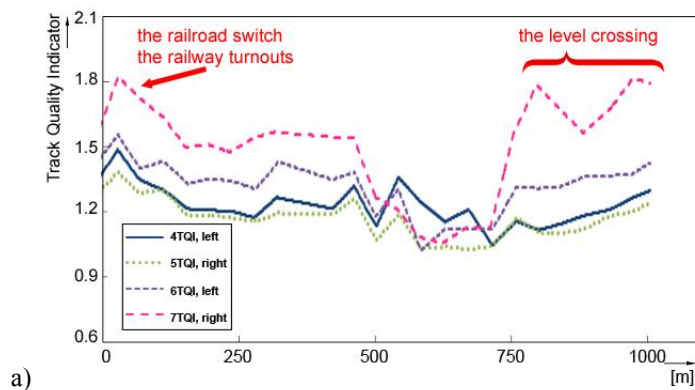


Figure 5: Track condition chart along 1 km near Sochaczew on January 25<sup>th</sup>, 2012 in the case of B-bogie – comparing the values of track quality indicator obtained on the right and the left rails

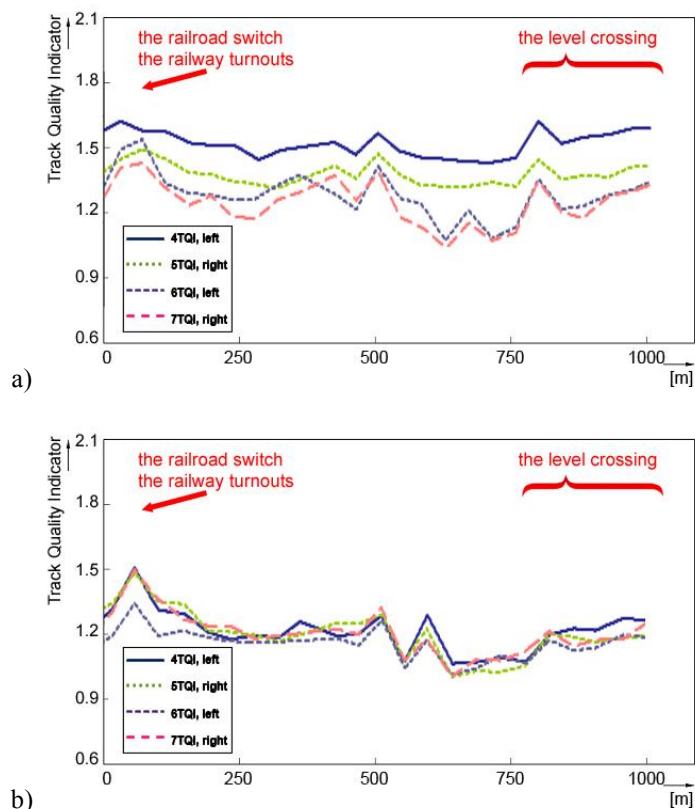


Figure 6: Track condition chart along 1 km near Sochaczew on January 25<sup>th</sup>, 2012 in the case of a) C-bogie, b) D-bogie – comparing the values of track quality indicator obtained on the right and the left rails

## CONCLUSION

The system proposed in this paper fulfils partially essential tasks of monitoring system connected to existence, location, type and severity of damage. Besides those, the presented system forms an economical and efficient alternative for monitoring systems (installed both on specialised vehicle or as specialised devices) on used for track condition monitoring and checking.

The following conclusions can be drawn. It is possible to establish a diagnostic parameter defining the actual health of a track – it is track quality indicator (this measurement parameter might be sensitive to quality of vehicle and its velocity – therefore the research should be continued). By comparing the results obtained during a long enough period of time, it is also possible to assess the objects' cost of life, taking into account history of events and wear tendencies.

The presented system form can be an economical and efficient alternative for on-board monitoring systems used for railway vehicles with active suspensions.

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