PROBLEMY KOLEJNICTWA
RAILWAY REPORT Issue 185 (December 2019)
INSTYTUT KOLEJNICTWA
DOI: 10.36137/1858E
ISSN 0552-2145 (print) ISSN 2544-9451 (on-line)

Identifying Rail Running Surface Defects by Means of Vibroacoustic Signals

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Summary

The article presents the concept of a method to identify the most common defects occurring on the rail running surface using vibroacoustic signals. The article provides a description of rail defects, such as: squat, running surface defect and wheelburns. It covers the methodology adopted in the conducted research and the results of analyses of recorded signals for the technical–operating conditions occurring on railway lines no. 213 Reda – Hel and no. 131 Chorzów Batory – Tczew. The presented results of vibration and noise measurements concern recorded signals for defective track sections and for control track sections. The conducted synthesis of research findings proves the legitimacy of developing a method involving the use of vibration signals for the purpose of diagnosing the rail running surface, and indicates an opportunity to take advantage of vibroacoustic signals to evaluate the condition of other elements of track superstructure.

Keywords: vibroacoustics, vibration signals, rail defects

1. Introduction

Running surface defects are a significant problem affecting the safety of railway traffic management. The number of rails found to be broken and cracked on operational railway lines in Poland is increasing by the year. Effective diagnostics of the condition of rail running surfaces is an essential factor in improving the level of safety of railway transportation.

The article describes a concept of how to take advantage of vibroacoustic signals to determine the condition of the rail running surface and how to identify the occurring defects (damage). The research was conducted on two railway lines, no. 213 Reda – Hel and no. 131 Chorzów Batory – Tczew, at eight measurement points, analysing the three most common defects of the rail running surface. An analysis of vibration signals was performed on the following running surface defects: wheelburns (defect no. 2251), squat (defect no. 227), and defect no. 221 – running surface defect.

Wheelburns is damage found on the running surface of a railresulting entirely from the standard use and operation of isolated rail sections (Fig. 1a). Wheelburns looks like localised longitudinal wear on the running surface of a rail, in the form of lines reaching up to 1.5 m in length. Wheelburns occurs in crucial parts of track systems, e.g. before home signals, where trains brake violently or where heavy freight trains are accelerated to operational speed, as well as before level crossings and turnouts. Wheelburns occurs on both isolated rail sections [5].

According to PLK's Catalogue of Rail Defects [5], squat no. 227 is defined as a crack and local indentation of a rail's running surface, occurring outside the rail ends. Squats occur most often on straight sections and on elevations of the grade up to 4.0‰ (Fig. 1b) [6].

At its earliest stage, a squat appears to be a dark semi-circular spot, often still without any cracks. Further stages of its development involve material peeling off and cracking. The lack of appropriate diagnostics of isolated rail sections, as well as no visual inspections and no application of proper preventive measures, may lead to rails breaking completely and trains derailing. The causes of this type of defect [6] are not fully known, hence it is important to arrange for appropriate diagnostics involving, among others, careful visual inspections of the occurring defects [6].

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a) b)

Fig. 1. Rail wheelburns (a) and rail squat (b) [authors' own work]

The last of the analysed defects is the rail running surface defect no. 221, according to PLK's Catalogue of Rail Defects (Fig. 2). Defect no. 221 is a defect of metallurgical origin. It appears on the rail web during the standard use and operation of the track. Its most common manifestations include shelling of the running surface or groove-shaped cracks.

Fig. 2. Defect 221 – running surface damage [authors' own work]

Damage no. 221 is identified most often by means of visual inspection. Depending on the degree of defect development, the recommendation is to inspect the rail visually on a continuous basis, grind it or resurface it.

The abilities to identify a defect and determine the degree of deterioration, as well as the steps to be taken, depend very often on the diagnostic technician's experience and knowledge, on the often subjective judgement, and on the conditions in which the inspection is performed. Taking advantage of vibroacoustic signals could make the evaluation of the condition of running surfaces and particular elements of the track superstructure quicker, more effective, and more accurate. Using vibroacoustic phenomena acting as a dynamic response of rails during train passage can let us evaluate the condition of the rail running surface, joints, fastenings, sleepers, and railroad ballast [6].

2. Research methodology

2.1. Location of measurement points

The research was carried out on two railway lines managed by PKP PLK S.A., on the premises of the Railway Track Development and Construction Unit [PL: Zakład Linii Kolejowych] in Gdynia. The scope of research, including the location, chainage and superstructure type, is specified in Table 1. The first of the analysed lines is railway line no. 213 Reda – Hel, found in the Pomeranian Voivodeship. It is a regional line, non-electrified and redeveloped in the period 2011–2015. Railway line no. 213 measures 62.827 km in length.

The second analysed line is railway line no. 131 Chorzów Batory – Tczew, which is the line with the highest volume of freight traffic in Poland, formerly referred to as the coal trunk-line. Line no. 131 measures 493.391 km in length, and its annual traffic intensity amounts to approximately 30 Tg.

The measurements were performed at eight measurement points for the two above-mentioned railway lines. There were at least ten measurements of vibration and noise for different train types taken at each point.

2.2. Scope of research

Vibration measurements were taken using a measurement system composed of two converters: a 4504A type three-axis vibration converter and a 4513-B-001 single-axis vibration converter. The three-axis converter was fitted to the rail web, and the single-axis converter was mounted underneath the rail foot (Fig. 3). The three-axis converter recorded signals in three directions: X – in line with the train movement, Y – transversely to the train movement, and Z – perpendicularly to the train movement.

Table 1

Vibroacoustic signal measurement points on railway lines no. 213 and no. 131

Measurement point name	Measurement date	Number of measurements	Investigated defect/damage	Track superstructure
213 – Control KM 30.900 LT	24. 06. 2017	10	control track section	S49 type rail, SB-3 fastening, PS – 93 sleepers
213 – 227 Squat KM 38.760 LT	26. 06. 2017	10	squat	
213 – 2251 Wheelburns KM 11.500 LT	27. 06. 2017	10	wheelburns	
213 – 221 Running surface defect KM 16.100 RT	1. 07. 2017	10	running surface defect	
131 – Control KM 458.900 RT	9.07.2017	14	control track section	60E1 type rail (2010), SB – 3 fastening, PS – 93 sleepers
131 – 227 Squat KM 466.150 LT	10.07. 2017	11	squat	
131 – 2251 Wheelburns KM 458.750 RT	11. 07. 2017	12	wheelburns	
131 – 221 Running surface defect KM 458.880 RT	13. 07. 2017	10	running surface defect	

[Authors' own work].

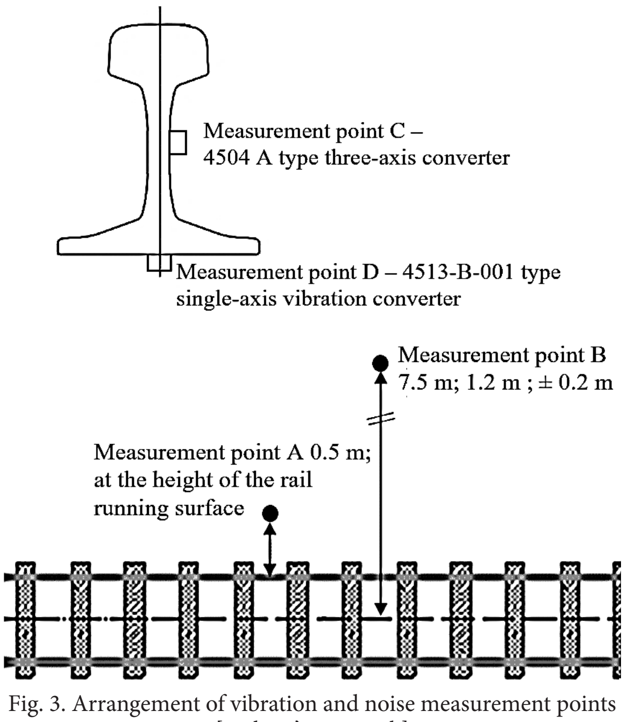

Fig. 3. Arrangement of vibration and noise measurement points [authors' own work]

Noise measurements were taken at two measurement points. Point A was located 0.5 m away from the outermost isolated rail section at the height of the running surface, and point B was located 7.5 m away from the track axis at the height of 1.2 m (Fig. 3). Noise measurements were performed according to [9, 11]. The measurements involved using capacitor microphones transmitting the recorded information to a recording module processing the data of each single acoustic event.

The first of the conducted noise measurement analyses was an analysis in the time domain. It was followed by a statistical analysis of point measures. Further analyses involved analysing particular patterns in the time domain taking the occurring background noise into account (Fig. 4).

After a preliminary selection of signals, the results obtained from the measurements of three-axis and single-axis sensor vibration were analysed in the time and frequency domains [2, 3]. The analysis in the time domain was carried out for acceleration, velocity and displacement – using PULSE Reflex 21 software. The results of the said analyses made it possible to define the aRMS value as the best carrier of information concerning the condition of the rail running surface.

The results of the performed analyses were discussed on the basis of individual graphs of the RMS values of acceleration as a function of time for each measurement point – taking each train passage into account. The next step was a frequency analysis carried out using a fast Fourier transform for aRMS values and a statistical analysis of point measures [3].

On account of the specificity of the converter and the way in which the converter was fixed to the rail, the average signal patterns were subject to filtering in the range of 20–10,000 Hz, according to the recommendations of the manufacturer of the vibration converters used. The next stage involved carrying out a spectrum analysis, which required the pattern of each instance of damage to be compared with the control track and the biggest differences in the acceleration values between the investigated damage and the control track to be found. The values of the identified maximum differences were compared to the frequency at which the investigated damage could only occur [1].

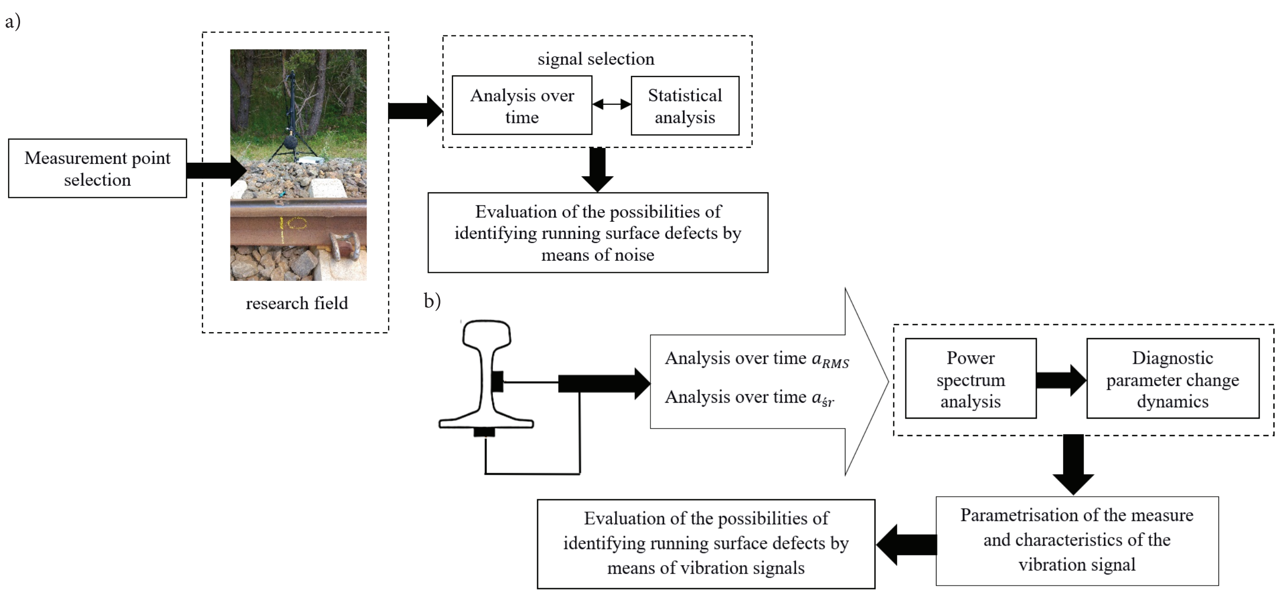

Fig. 4. Procedures of the analysis of vibroacoustic signals in the process of identifying running surface damage: a) acoustic analysis, b) vibration analysis: [authors' own work]

3. Measurement result analysis

3.1. Noise measurement result analysis

The results of the analysis of noise levels over time showed that similar noise values were recorded for each of the measurement points, taking the differences in the distances – i.e. 0.5 m and 7.5 m – into consideration. This made it possible to average the values occurring over time and determine the average noise level during train passage for a given measurement point (Fig. 5). Similar values of the occurring patterns also made it possible to find that the values of the recorded noise levels did not depend on the trainset or the speed relative to the number of passages taking place at a given measurement point [8].

When a train wheel passed over a squat, the noise level increased by approx. 13 dB at the measurement point located 0.5 m away from the rail. The highest noise values were recorded on the control track section (distance of 0.5 m), and the lowest noise values were found to occur on the section of the track with wheelburns (distance of 7.5 m) [10].

3.2. Vibration measurement result analysis

The analysis of the vibration measurement results was performed for two vibration measurement points – on the rail web and below the rail foot. The obtained results were analysed in the time and frequency domains. Figure 6 shows a sample result of a frequency analysis for the RMS values of acceleration on line no. 213 in direction Y – transversely to the train movement – for the three-axis sensor mounted on the rail web for particular defects [7].

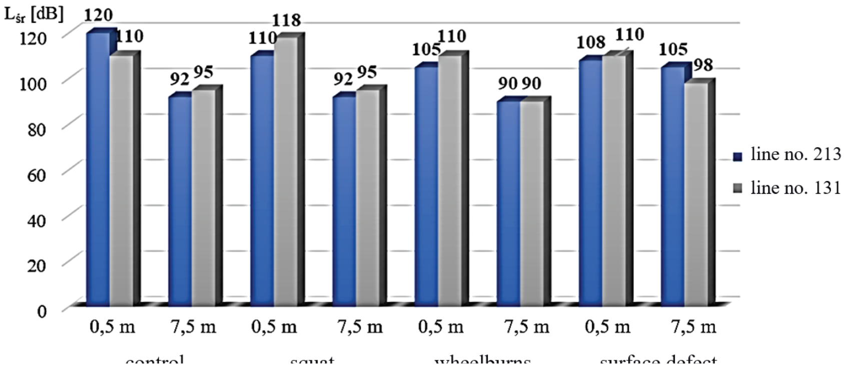

Fig. 5. Average noise level values recorded on lines no. 213 and 131 for different defects at two measurement points – 0.5 m and 7.5 m [authors' own work]

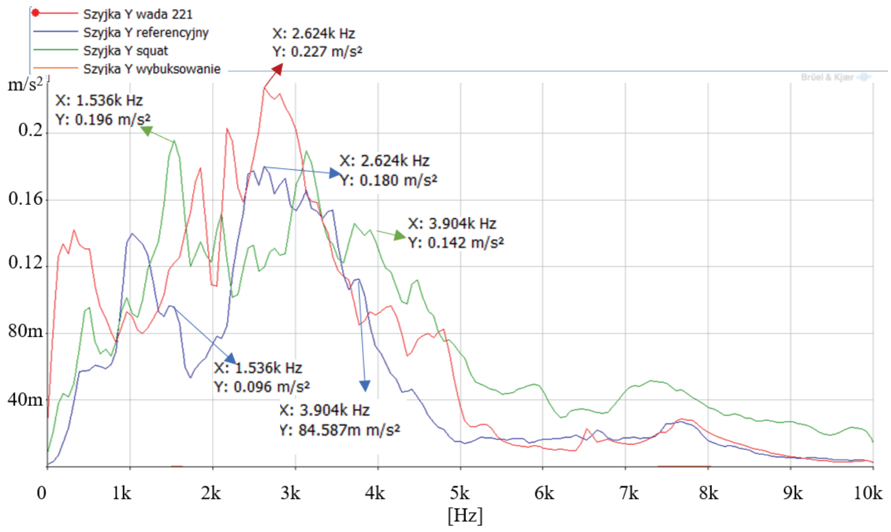

Fig. 6. The patterns of the RMS values of acceleration as a function of frequency for axis Y of the three-axis sensor on line no. 213 [authors' own work]

The spectrum analysis for each pattern was carried out in the range of 300 Hz–10,000 Hz, according to the manufacturer's recommendation.

The spectrum analysis of each recorded pattern served as the basis for drawing up a table (Table 2) that includes values of the frequencies at which the differences between the aRMS at a point with a certain defect and the aRMS at a point on the control track were the biggest. A comparison of frequency values made it possible to notice a strict correlation between the directions of the vibration signal and the results for the frequency range of the occurrence of certain defect types.

A squat defect can be found to occur on the three-axis sensor in the range of 3.7–4.5 kHz, and spalling tends to occur at a frequency of 5.6 kHz. It is hard to identify a running surface defect no. 221 due to the characteristics of the signal obtained as a result of measurement of the defect in question.

One of the additional ways to describe signals of displacement, velocity or acceleration of vibration is by using point measures. They make it possible to describe a vibration signal using one number. Point measures are applied in vibroacoustic diagnostics (VAD) to determine the changes occurring in a vibroacoustic signal [10].

Calculating the point measures for the RMS values of acceleration of the analysed patterns made it possible to determine the dynamics of changes in the diagnostic parameter. The article presents the diagnostic parameter change dynamics (DPCD; PL: DZPD) [dB] as a ratio of the point measure of a defective track section to the point measure of the control track section (1) [3].

$$DZPD = 20\log_{10}\left(\frac{\mu_u}{\mu_R}\right), \qquad (1)$$

where:

μ_R – point measure for the control track,

μ_u – point measure for the damaged (defective) track.

Table 2

Frequency values compiled in order to identify selected instances of damage of rail running surfac

Damage name	Three-axis converter			Single-axis converter
	axis X [kHz]	axis Y [kHz]	axis Z [kHz]	axis Z [kHz]
Railway line no. 213 Reda – Hel				
squat 227	3.7	3.9	3.8	1.2 and 6.7
wheelburns 2251	1–7.2 and 8–9	4.2–6.9	none	4.1–6.7
defect no. 221	7.6	2.6	1.2	6
Railway line no. 131 Chorzów Batory – Tczew				
defect no. 221	4.5	3.9	0.832	7.5
squat 227	7.5	none	5.6	8.8
wheelburns 2251	0.7–1.2	0.704	0.640	5.2

[Authors' own work].

Parametrisation of vibration signal measures made it possible to select and reject the vibration directions carrying the smallest amount of information about rail defects (Table 3).

On account of the highest diagnostic parameter change dynamics, the vibration measurement points became the points of the three-axis sensor in axis X – in line with railbound vehicle movement, and in axis Z – perpendicular to railbound vehicle movement.

Based on the findings given in Table 3, it was possible to determine the direction of the vibration signal of the highest diagnostic parameter change dynamics, i.e. direction Z – perpendicular to railbound vehicle movement, measured fixed to the rail web. The direction provides the biggest amount of information already at the stage of analysis of signal patterns over time [7].

4. Conclusions

Based on the research results, it has been found that it is possible to evaluate the condition of the rail running surface by referring to vibration parameters, especially vibrations measured on the rail web. The performed analysis of vibroacoustic signals shows that the type of rail vehicle and its speed do not affect the measured values of vibration signals. Thus, the evaluation of the rail running surface condition may take place during the passage of different types of trains travelling at different speeds. Further research into vibroacoustic phenomena in the context of identifying rail running surface defects should focus on extending the measurement database to include other railway lines and superstructures not featured in the database so far – taking non-standard track superstructures into consideration as well. Finally, evaluating the condition of the rail running surface by taking advantage of vibroacoustic phenomena should utilise information transmitted by the vibration signal coming from the casing of a wheelset bearing of a railbound vehicle inspecting the condition of rails – such as a measuring vehicle.

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Table 3

Diagnostic parameter change dynamics (DPCD) depending on the vibration direction

Damage name	DPCD [dB] Axis X	DPCD [dB] Axis Y	DPCD [dB] Axis Z	DPCD [dB] Foot
Railway line no. 213 Reda – Hel				
defect no. 221	46.60	2.02	4.11	1.92
squat 227	4.31	1.58	1.85	1.94
wheelburns 2251	31.04	54.94	49.27	56.04
Damage name	**DPCD [dB] Axis X**	**DPCD [dB] Axis Y**	**DPCD [dB] Axis Z**	**DPCD [dB] Foot**
Railway line no. 131 Chorzów Batory – Tczew				
defect no. 221	7.42	9.42	8.15	5.84
squat 227	3.99	10.88	9.81	8.02
wheelburns 2251	0.56	0.37	1.67	0.30

[Authors' own work].

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