Assesment of The EMU and Track Condition Monitoring Results from Chosen Track Sections During Normal Operation

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The paper contains analyses of the recorded acceleration signals obtained from the prototype of the rail vehicle suspension condition and track condition monitoring system. Primary and secondary suspension condition is assessed upon acceleration signals registered in measuring points located on bogie frames and vehicle body. The prototype is installed on electric multiple unit (EMU). Data was registered during normal operation of the vehicle on selected sections of one of the main rail lines in Poland. The aim of the analyses is to examine relation between proposed statistical parameters and normative parameters included in rail standards (UIC 518, EN 14363). The analyses were performed generally in cases of exceeding normative parameters values.
The problem of assessment of results as well as monitoring system prototype are parts of research project 'MONIT - MONITORING OF TECHNICAL STATE OF CONSTRUCTION AND EVALUATION OF ITS LIFESPAN'.
Keywords: monitoring, suspension.

1. INTRODUCTION

The development of measurement techniques and the tendency to increase the operating speed of rail transport, while raising the level of safety, is the reason for the development of vehicle monitoring systems. Currently used monitoring methods of the rail vehicles represent monitoring systems directly related to the control of the vehicle, such as power supply, power train, braking system. Application of monitoring systems allows to increase safety through early detection of malfunctions in selected vehicle systems, and prediction of the future state. This allows to perform early repairs and to reduce costs in case of unexpected failures. It can be added that the use of monitoring has also economic significance.

In case of high-speed rail vehicles it is now mandatory to monitor axle bearing temperature. It is expected that in the near future the requirements for the rail vehicle monitoring systems will increase [1]. This is also affected by the specificity of the rail transport. The engine-driver operating multiple unit or train consisting of many wagons may not perceive abnormal behavior of the distant wagons. Therefore, due to safety, the driver and special staff should be informed on technical condition of the train.

Vehicle suspension determines significantly riding dynamics, safety and comfort. The suspension condition should be checked regularly, and even monitored continuously. According to current knowledge, there is no commercial system that allows the monitoring of primary and secondary suspension condition. In terms of active safety, maintaining suspension in proper condition is an issue of high importance.

The prototype of the rail vehicle's suspension monitoring system has been developed at Monitoring of Technical State of Construction and Evaluation of its Lifespan Project (MONIT).

The results of the analysis in the paper were obtained from data which are the acceleration signals recorded by the monitoring system prototype installed on electric multiple unit (EMU) ED74. ED74 is produced by PESA Bydgoszcz SA company.

2. THE MONITORING CHARACTERISTIC

The monitoring system of the vehicle and the track is characterized by versatility and modular architecture. Its aim is qualitative assessment of the primary and secondary suspension , axle bearing temperature measurement and evaluation of track quality.

The system installed on the ED74 EMU contains:

- Central data acquisition computer MOXA V2406-XPE,
- Sierra Wireless AirLink GX400 router with GPS module,
- 5 local data acquisition units,
- 50 VIS-311A accelerometers,
- 20 Pt100 temperature sensors,
- System server with operator's station.

For the primary suspension assessment accelerometers installed on the bogies frames (above wheels) are used. Regarding the system's architecture and cost of the equipment, the number of measuring points is reduced to two. Acceleration signals are recorded in this points in lateral and vertical direction. Secondary suspension condition assessment is based on acceleration signals recorded in lateral and vertical direction on the vehicle body, above bogie center. Jacobs bogies are installed between car body sections, therefore measurement points are located at the ends of the body sections. It should be noted that the configuration of the sensors on motor bogie 'E' and body section 'E' is different from the others – there are no accelerometers recording signals in the lateral direction.

The monitoring system, basing on the acceleration signals recorded on the axles boxes, computes the track quality indicator. In addition, temperature of the axle box bearings is measured. Through a local data acquisition unit (LDAQ) signals are transmitted from the sensors to a central acquisition unit (CDAQ). One LDAQ unit performs signals conditioning from one bogie and one body section. Signals from LDAQ are transmitted to CDAQ and the diagnostic parameters are computed by its processor. Central data acquisition unit contains GPS and GSM modules.

The signals from all sensors are collected in the form of a data packet at each kilometer. The data packet contains geographic coordinates of place, where the signals recording was triggered. In case of the exceedance of the diagnostic parameters' limit values, a control packet is generated containing information on the exceedance. Packets are sent to the operator's station (system's server) via GSM network, where information appears as warnings and alerts referring to the vehicle's condition.

The ED74 is equipped with 5 LDAQ for each bogie. The system architecture is shown in Fig. 1.

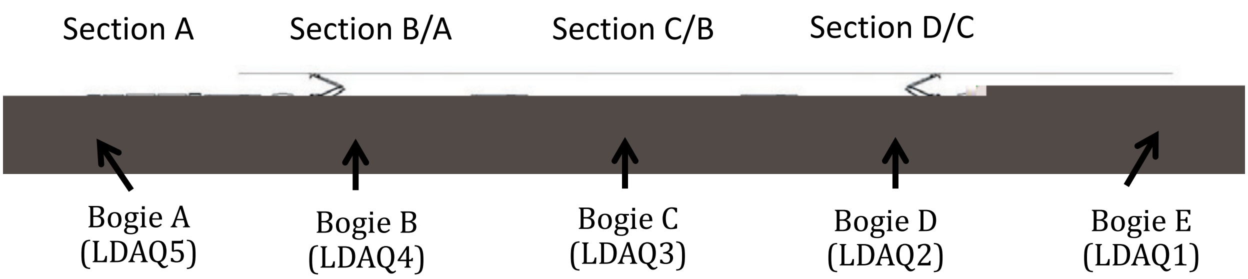

Fig. 1. The scheme of ED74 electric multiple unit

3. THE MONITORING PROCEDURE

Suspension fault detection method for the monitoring system should be efficient, easy to implement and fast. There are a few methods, e.g. based on Kalman Filter [3], [4] and multi-model approach [5], [6], which are intended to solve the problem of suspension fault detection. Nevertheless, no information could be found on the implementation of these methods in the real monitoring systems. It may be concluded that proposed methods have been tested numerically only. The main disadvantage of these methods is necessity of building an accurate vehicle model, characterized by stiffness and damping coefficient, as well as masses and moments of inertia. In the modeling phase, unavoidable simplification are implemented, which affect fault detection effectiveness. Moreover, access to these parameters is difficult or impossible, since vehicle manufacturer may not reveal such accurate information due to business secrecy.

Although the number of sensors is optimal, the monitoring system installed on ED74 uses a significant number of measuring channels (due to the complexity of the vehicle). The analysis of signals and the sending of data/control packets to the server in short time sets high requirements to hardware. Despite significant progress in the field of wireless communications and industrial computers, performance of the currently available devices may not be sufficient for effective operation of the monitoring system. Taking into account this fact, it was decided to use a method based on a statistical analysis of signals, which meets the demands of ease of implementation and fast analysis [2]. Parameters for vehicle condition monitoring, which are used in the paper, are listed below:

- Root mean square (RMS),
- Zero-Peak,
- Kurtosis,
- Interquartile range (IQR).

RMS and Zero-Peak are described in the standards [7], [8] for testing and approval of rail vehicles from the point of their dynamic behavior. It should be noted that Zero-Peak is a value of percentile 99.85%.

There are two diagnostic levels in the monitoring procedure (fig. 2). On the first level current RMS and Zero-Peak values are compared to the normative ones. On the second level, parameters which are not included in [7] and [8] are used. The nominal values of second-level parameters may be set during test rides of the new vehicles in nominal condition.

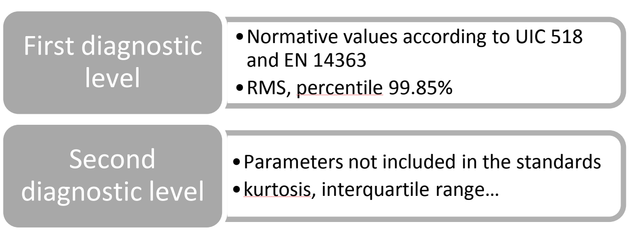

Fig. 2. The diagnostic levels of diagnostic procedure

The measuring points, chosen parameter's limit values and the filters' cut-off frequencies are in table 1.

Table 1. RMS and Zero-Peak limit values of acceleration signals with filters' cut-off frequencies (source: [7], [8])

Measurement point location	Direction	Zero-Peak [m/s^2]	RMS [m/s^2]	Filter [Hz]
Body	Lateral	2.5[1)]	0.5[1)]	0.4÷10
	Vertical	2.5[1)]	0.75[1)]	0.4÷10
Bogie frame	Lateral	10.9[2)]	5[2)]	10
	Vertical	20[3)]	7[3)]	20

Track condition monitoring is performer by means of acceleration signals recorded on the axle boxes. A track quality indicator is described by formula (1)

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

where:
c_t = 1, value set on the basis of the numerical research,
p = 0.225, value set on the basis of the numerical research,
a – vector of filtered acceleration signal.

Signals recording, on one kilometer-long track sections, is triggered under conditions:

- Minimal velocity is reached
- Constant velocity (with permissible deviations)

When these requirements are met, the measurement is performed in almost steady conditions. The results are grouped regarding velocity ranges. Each range can have different limit values – i.e. different values for e.g. 70 - 90, 90 - 110,..., 150 - 160 km/h. Constant velocity is usually achieved on track lines beyond cities, on the other hand in cities it varies more often, therefore data packets are not frequently formed.

4. RESULTS OF EMU CONDITION MONITORING

EMU with installed monitoring system belongs to PKP (Polish National Railways) Intercity operator. The analysis was carried out on data obtained from the Warsaw – Cracow railway line, obtained on the following days:

- 10.01.2012 Cracow – Warsaw
- 12.01.2012 Warsaw – Cracow
- 18.01.2012 Cracow – Warsaw
- 29.01.2012 Warsaw – Cracow
- 31.01.2012 Cracow – Warsaw

Due to substantial number of results, the mean values of calculated parameters are presented. The tables 2 and 3 contain statistics of normative values exceedances for the following measurement channels, concerning Warsaw – Cracow line. The line entitled 'Packets with exceedances contains number of packets with recorded exceedances of RMS and/or Zero-Peak relative to the entire number of packets for the bogie/body section.

Table 2. Exceedances of Zero-Peak for the bogie and body channels on 12-01-2012, Warsaw – Cracow relation

Zero-Peak					
Bogie	**A**	**B**	**C**	**D**	**E**
left side, vertical	9	220	178	202	210
left side, lateral	5	56	40	49	
right side, vertical	5	169	192	0	173
right side, lateral	0	65	71	55	
Body section	**A**	**B/A**	**C/B**	**D/C**	**E**
vertical	101	26	13	61	144
lateral	10	0	0	13	
Packets with exceed.	**27/5**	**20/52**	**19/52**	**14/52**	**24/36**

Table 3. Exceedances of RMS for the bogie and body channels on 12-01-2012, Warsaw – Cracow relation

RMS					
Bogie	**A**	**B**	**C**	**D**	**E**
lleft side, vertical	0	0	0	0	0
left side, lateral	0	0	0	0	
right side, vertical	0	0	0	0	0
left side, lateral	0	0	0	0	
Body section	**A**	**B/A**	**C/B**	**D/C**	**E**
vertical	1	0	0	1	23
lateral	0	0	2	8	
Packets with exceed.	**1/5**	**0/52**	**2/52**	**8/52**	**2/35**

The average parameters values of vertical acceleration signals recorded on bogie ‘E’ are depicted in fig. 3 – 6. Distribution of average RMS, IQR and Zero-Peak values are congruent. The limit values of RMS (7 [m/s^2]) and Zero-Peak (20 [m/s^2]), according to table 1, were not exceeded.

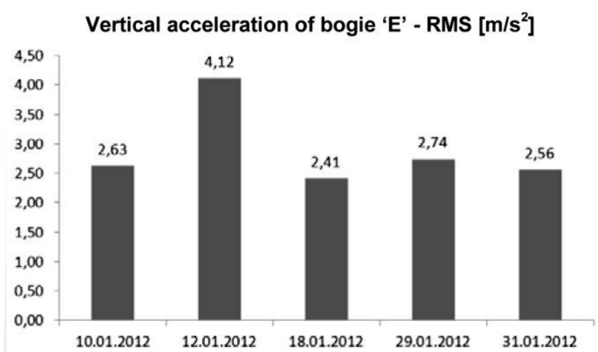

Fig. 3. RMS values - vertical acceleration of bogie ‘E’ on chosen days for analysis

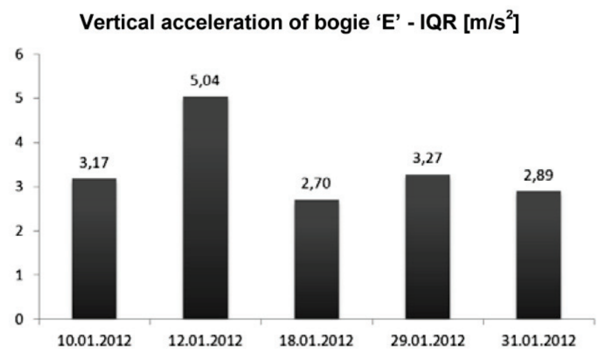

Fig. 4. IQR values - vertical acceleration of bogie ‘E’ on chosen days for analysis

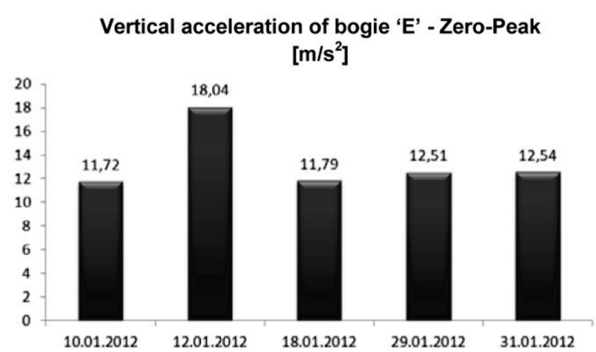

Fig. 5. Zero-Peak values - vertical acceleration of bogie ‘E’ on chosen days for analysis

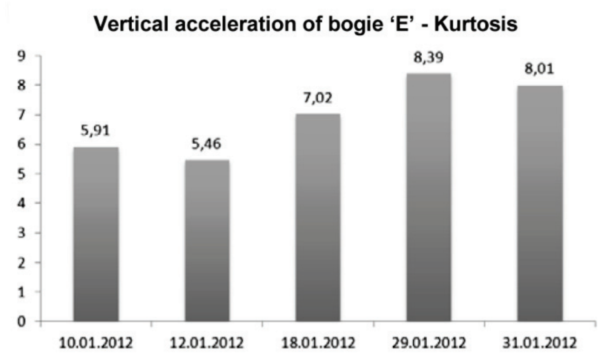

Fig. 6. Kurtosis values - vertical acceleration of bogie 'E' on chosen days for analysis

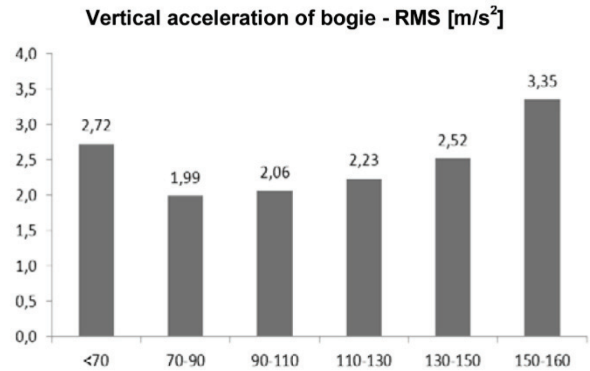

Fig. 8. RMS values of vertical acceleration of bogie related to speed [km/h]

The number of generated data packets depends on the vehicle's velocity (fig. 7). For higher values of velocity more packets are generated due to almost constant measurement conditions – the packet generation condition is satisfied.

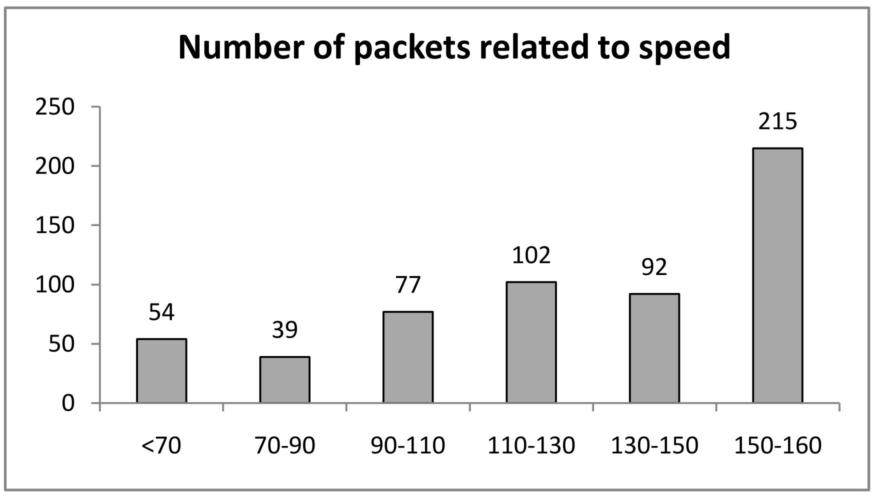

Fig. 7. Dependance of packets number on speed [km/h]

Velocity influence on parameters' values is particularly observed below 70 km/h and for 150 – 160 km/h (maximal velocity of EMU). The lower speed values results from operating in city areas (turnouts, crossings, stations) or travelling on track sections of poor maintenance quality. Velocity values near maximal cause higher frequency excitations that increase RMS (fig. 8) and Zero-Peak (fig. 10) values. It should be noted that, kurtosis distribution (fig. 9, fig. 11) contains higher values, both for bogies and body, for the particular velocity ranges mentioned above. This fact may indicate little concentration around mean value. Due to abrupt excitations (jointed track, turnouts, etc), signal contained values, which differed significantly from mean value.

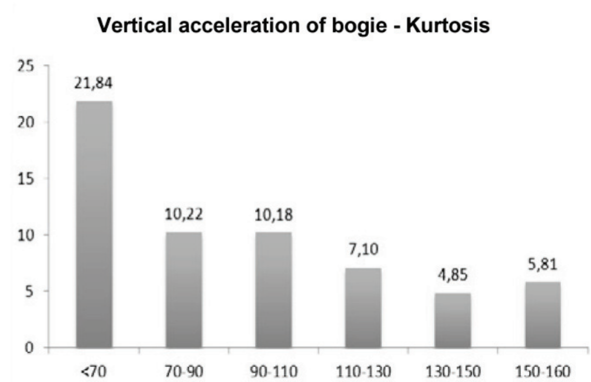

Fig. 9. Kurtosis values of vertical acceleration of bogie related to speed [km/h]

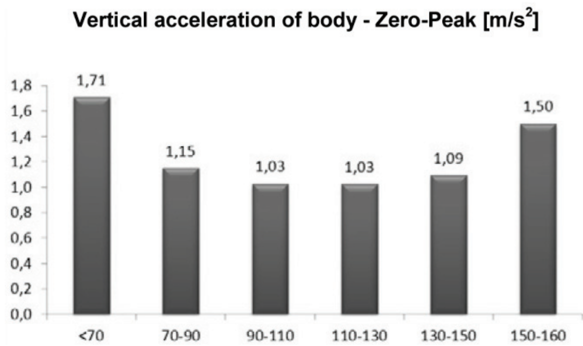

Fig. 10. Zero-Peak values of vertical acceleration of body related to speed [km/h]

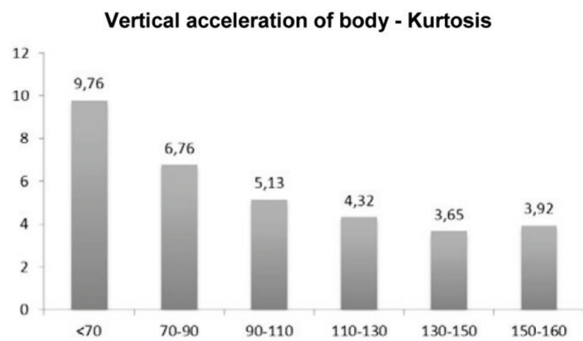

Fig. 11. Kurtosis values of vertical acceleration of body related to speed [km/h]

Mean value of track quality indicator for the velocity ranges is shown in fig. 12. For the range from 130 to 150 km/h, higher value for left side has been recorded. This value may unreliable, since during vehicle inspection it was noted, that the accelerometer had been inclined. Ignoring this fact, it can be considered, that at lower velocity v<90 km/h, indicator's value is the highest. It can result from moving on deteriorated track section with speed limits. For higher speed indicator value is nearly constant, ca. 1.25.

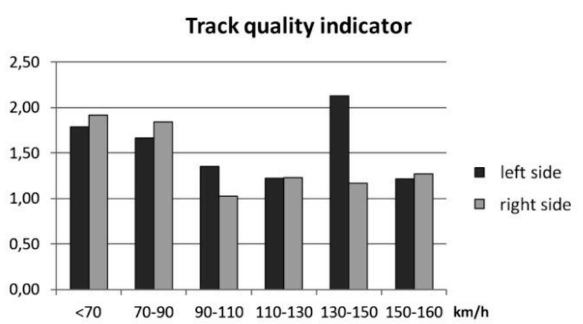

Fig. 12. The track quality indicator's values for left and right rail assessed by the monitoring system

RMS and IQR of vertical acceleration signal recorded on bogie 'E' on January 31st are presented in fig. 13. The limit value of RMS (7 [m/s^2]) was not exceeded. Interquartile range values were generally higher than RMS ones (except for 12th, 14th and 19th packet).

Kurtosis distribution of the signals from one measuring point is depicted in fig. 14.

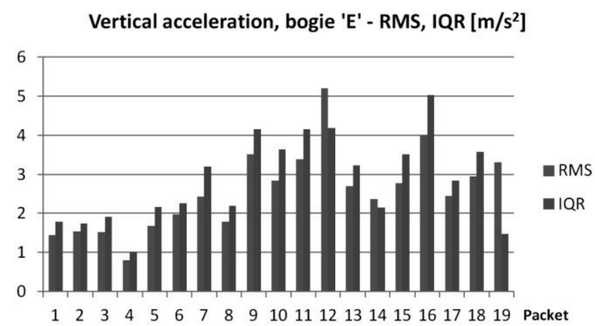

Fig. 13. RMS and IQR values of vertical acceleration on bogie 'E' - 31st of January 2012

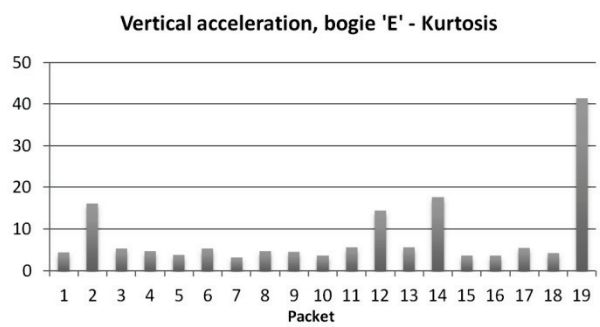

Fig. 14. Kurtosis values of vertical acceleration on bogie 'E' - January 31st 2012

On 18.01.2012 a significant exceedance of RMS limit value was recorded on the body (B/A section), in lateral direction at 60 km/h. It can be concluded that the exceedance was an effect of transient sensor. RMS value reached nearly 3 [m/s^2] (second packet) while the limit is 0.5 [m/s^2]. Such great exceedance was not recorded on the other body sections and during further exploitation. IQR values in second packet were on a proper level.

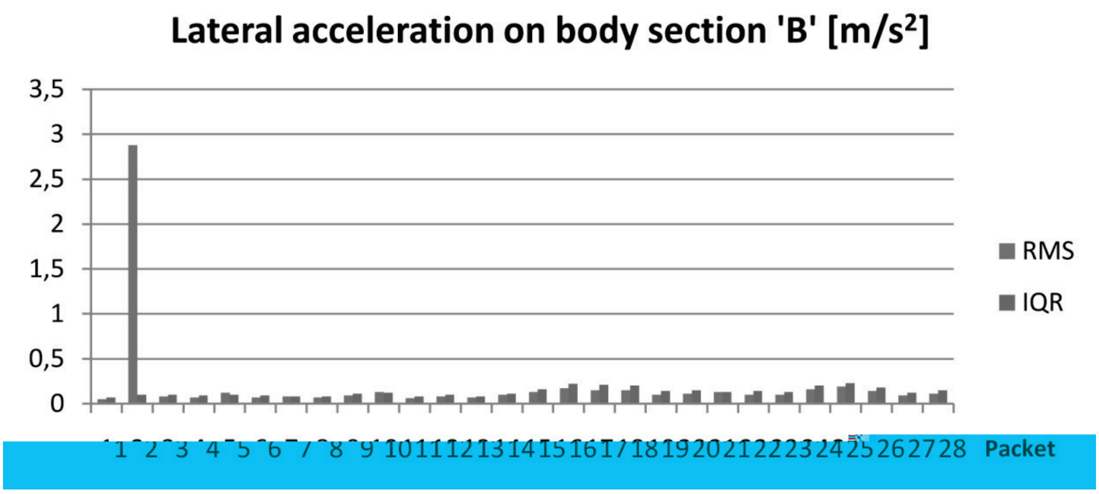

Fig. 15. The exceedance of RMS limit value on body in lateral direction recorded in second packet

5. CONCLUSIONS

The statistical parameters and their normative limit values were used in the process of the rail vehicle condition monitoring. Contrary to guidelines in [7] and [8], calculation of the parameters was performed on data collected on 1 kilometer-long track sections. Nonetheless, the RMS limit values from [7] and [8] may be implemented in the monitoring system. Kurtosis and interquartile range were applied to the second diagnostic level.

The monitoring of the EMU in nominal condition indicated low number of RMS exceedance on the chosen rail line. This occurred mainly at speed near V_{max}=160 km/h. For the majority of generated packets, the limit values were only slightly exceeded.

The monitoring system recorded many exceedances of Zero-Peak limit value, both for signals obtained from bogie frames and body. Analyzing signals contained in one packet (limited distance of 1 km), many instantaneous exceedances can be seen. The diagnostic inference based on Zero-Peak value cannot proceed. For the monitoring purpose, this parameter should be implement along with other, not analyzed separately.

The IQR distribution over the packets is compared to this of RMS. IQR values generally are higher than RMS values. Interquartile range, being equal to the difference between the upper and lower quartiles, rejects small and big values from observation as it illustrated in fig. 15. This feature is favorable when random noise occurs.

A signal kurtosis characterizes degree of concentration around mean value. In case of random excitations it is difficult to assess vehicle condition using this parameter. Analyzing average kurtosis values (upon many rides) it can be concluded, that for V<70 km/h its values are greater than for other speed ranges. Kurtosis does not provide relevant diagnostic information on running gear condition.

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