Comparison of simulation analysis results and experiment results for monitoring system of rail vehicle's suspension flexible parts

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The aim of the paper is to present results of an experiment and a simulation in order to obtain some information on dynamical responses of damaged suspension in rail vehicles. The experiment was done on passenger and freight car. The faults introduced to suspension are: reduction of stiffness in primary suspension and loss of damper in secondary suspension. Obtained results from the experiment were compared to simulation results.

Introduction

The tendency of improving passive and active safety of rail vehicles has been developed intensively for the last years. Although rail transport is one the safest, serious accidents, which have strong impact on environment and infrastructure, also occur. Another factor, which rises demands on safety is establishment of high-speed rail networks. One of the solutions of minimizing risk of accidents and assuring regular transport services is the application of condition monitoring of vehicle's crucial elements. The condition monitoring system indicates improper elements functioning, so the operator may take decisions to plan service of vehicle before accident occurs. The economic aspects also should be taken into account, since early detection of fault can reduce reparation costs and prevent from further deterioration. The elements that are undoubtedly important for providing both running safety and comfort are springs and dampers of primary and secondary suspension. Damages of suspension determine uneven wheel load. This phenomenon increases wear of wheel and its flange, rail, deteriorates running behaviour and comfort. The decreased vehicle's dynamic properties may lead to derailment in extreme cases **[6]**. Thus suspension monitoring system would increase active safety by minimizing risk of accidents.

Due to difficulties in suspension's condition analyzing and lack of such a system for commercial use, the issue of suspension condition monitoring is still non mandatory for manufacturers. However, since safety is a priority in railway transport, the problem of fault detection and condition monitoring of rail vehicle suspension is being solved by many research centers worldwide **[1, 2, 4, 7**]. The prototype of the rail vehicle's suspension monitoring system has been developed at project 'MONIT'. The monitoring system has been tested on passenger and freight cars that were running on test track near Zmigrod. The two technical states of suspension were examined for both cars in two kind of suspension condition: undamaged and damaged.

The aim of this study is to compare simulation analysis results and results obtained from the experiment on test track.

Monitoring procedure

The monitoring procedure in terms of the running gear's dynamic properties point of view is based on the requirements described in UIC 518 **[3]** code and in the standard EN 14363**[5]**. These documents contain guidelines for running behaviour and safety. The assessment of the above properties is done by comparing accelerations measured on bogie and body to the limit values. The monitoring procedure developed at project 'MONIT' complies to these documents in terms of measuring points location and acceleration limit values.

For more accurate diagnosis it is assumed that algorithm of suspension condition assessment should also be based on comparison of other diagnostic parameters characterizing registered signals. Faults of springs and dampers cause changes of acceleration signals which make differences between assumed signal's diagnostic parameters for vehicle in nominal and damaged state. The excess of assumed parameter's limit value for nominal vehicle would indicate existing fault in vehicle suspension.

The monitoring system registers signals during normal operation (at constant velocity), on 1 kilometer long distances, i.e. the measurement is being done during running on 1 km distances, registered data are formed into a package which is sent to the operator's server. After that another measurement is triggered. The acceleration signals are being sampled at frequency of 1500 Hz. This signal is then resampled to the spatial frequency of 0.2 m.

Acceleration of a bogie frame is measured on its front right and left rear end in lateral (y) and vertical (z) direction, above wheelsets. Body accelerations are registered on a floor level, above the bogie centre, both in lateral and vertical direction (*Figure 1*). The system should be as simple as possible, so the number of accelerometers is minimal for that purpose. This also involves economical aspects, since this system must be affordable and attractive for the operators.

Recognizing suspension condition during normal operation is a difficult task. While as-sessing signals, we should keep in mind that there are many excitation

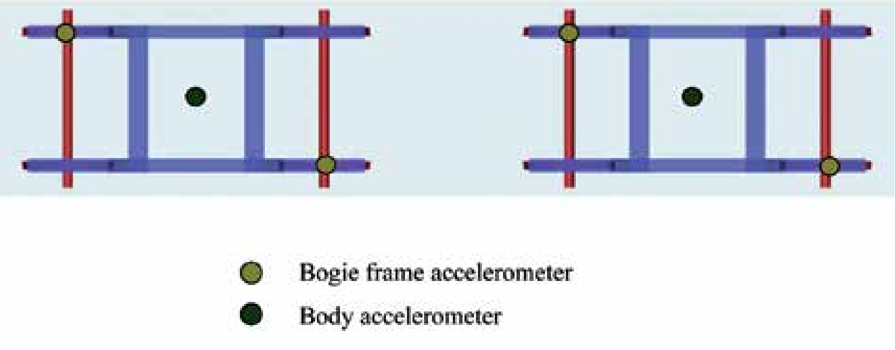

Fig. 1. **location of measuring points**

sources that may alter signal to the such pitch, that suspension may be classified as damaged. It may happen when vehicle is travelling on a track which state of maintenance changes rapidly or there are parts of rail infrastructure such as turnouts. Nevertheless, the measurement is done on 1 km distances, so peaks of high amplitude should be treated as random events and will be filtered and smoothed while analysing. In this paper there are introduced some statistical parameters that may help with assessing technical state of suspension. The parameters are also used in order to compare real-track tests to simulation ones. This parameters are listed below:

- root mean square (RMS).
- coefficient of variation (CoV),
- interquartile range (IQR),
- kurtosis,
- signal energy,
- variance

Experiment on a test track

The experiment was performed on test track near Zmigrod in Poland. The monitoring system have been tested on passenger and freight car (coal car). The passenger wagon uses 4ANc bogies. and coal car, loaded up to 90 t, utilises 25TN bogies (polish variant of Y25). The first stage of the experiment was carried on vehicles in nominal state (without suspension damages). The second stage included the same wagons but with suspension damages.

In case of the passenger car, damper of secondary suspension system was removed (*Figure 2*). The fault is expected to be shown when signal from body accelerometer is considered.

Suspension in the freight car was damaged by taking out one coaxial packet of springs between first wheelset and leading bogie on the left side (*Figure 3*). It should be noted, that in mentioned location, there is no accelerometer (there are only two points on the bogie frame with accelerometers). The nearest accelerometer, which could detect fault is located above second wheelset, on the left side.

Simulation tests

Simulation tests were carried out by means of VI-RAIL software. This application uses MSC.ADAMS simulation environment to per-form analysis of rail vehicles' dynamic behaviour. The main elements of vehicle, such as body, bogies, wheelsets are represented by stiff bodies which are connected together with massless models of dampers and springs. The software allows user to choose method of calculating forces between wheel and rail.

The suspension damages of passenger and coal car are modeled in the same manner as it was done during experimental tests – corre-sponding models of suspension components were removed.

The test track was modeled as rigid in VI-RAIL. The longitudinal profile complies to the real track. However, the accurate values of the irregularities of the entire real track were not available during performing simulations, it was assumed that, in case of lack of the irregularities, the known ones are repeated.

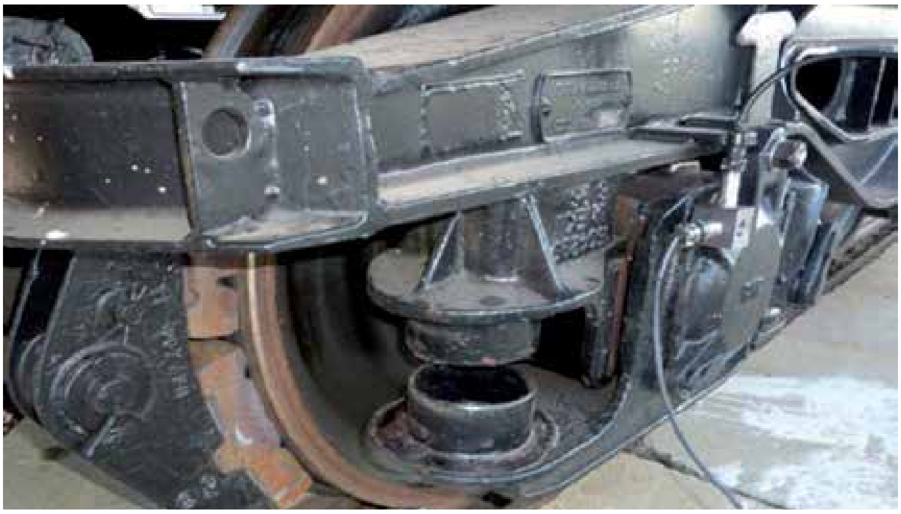

Fig. 2. **Freight car bogie with removed springs**

Fig. 3. **Passenger car running gear with secondary suspension damper disconnected**

Table 1. **Relative changes of parameters of the coal car's bogie acceleration, v = 60 km/h, loss of stiffness in primary suspension**

	Lateral acc. change [%]		Vertical acc. change [%]	
Parameter	**Experiment**	**Simulation**	**Experiment**	**Simulation**
IQR	5,8	3,2	2,2	24,5
Kurtosis	77,1	0,6	436,0	27,2
CoV	51,7	167,7	210,8	2748,6
RMS	4,9	3,9	1,9	21,0
Signal energy	9,0	8,0	4,4	46,4
Variance	9,6	8,0	3,8	46,4

Table 2. **Relative changes of parameters of the coal car's bogie acceleration, v = 80 km/h, loss of stiffness in primary suspension**

	Lateral acc. change [%]		Vertical acc. change [%]	
Parameter	**Experiment**	**Simulation**	**Experiment**	**Simulation**
IQR	4,3	0,8	15,4	3,4
Kurtosis	3,9	19,4	31,7	43,8
CoV	254,1	331,3	233,5	27,6
RMS	11,1	3,5	16,9	4,4
Signal energy	23,8	7,1	37,1	8,6
Variance	23,4	7,1	36,7	8,6

Table 3. **Relative changes of parameters of the passenger car's body acceleration, v = 80 km/h, loss of damper in secondary suspension**

	Lateral acc. change [%]		Vertical acc. change [%]	
Parameter	**Experiment**	**Simulation**	**Experiment**	**Simulation**
IQR	14,5	254,0	32,1	188,4
Kurtosis	86,5	104,2	27,8	105,9
CoV	96,9	28,2	30,7	473,7
RMS	5,1	202,3	28,6	154,9
Signal energy	12,0	814,6	68,0	549,5
Variance	9,1	813,6	65,8	549,5

Table 4. **Relative changes of parameters of the passenger car's body acceleration, v = 100 km/h, loss of damper in secondary suspension**

	Lateral acc. change [%]		Vertical acc. change [%]	
Parameter	**Experiment**	**Simulation**	**Experiment**	**Simulation**
IQR	9,9	3,3	1,6	25,2
Kurtosis	25,6	9,8	102,1	339,1
CoV	114,7	3,5	14,7	50,7
RMS	6,7	2,9	8,5	22,1
Signal energy	13,5	5,9	17,0	49,0
Variance	13,4	5,9	17,7	49,1

Analysis of the results

The results presented in this paragraph refer to tests performed at speed of 60 and 80 km/h in case of coal car and 80 and 100 km/h in case of passenger car. Representative results were obtained from section that consists of curve and tangent track.

The comparison of results for coal car are presented in *Table 1* and *Table 2*, for 60 and 80 km/h respectively. As mentioned in point 3, the signals registered from accelerometer above second wheelset are considered

The changes of diagnostic parameters for dis-connected damper in secondary suspension are illustrated in *Table 3* and *Table4*. The analyzed signals have been registered on the vehicle's body, above the bogie center.

Conclusions

The results of experimental tests and simulation show that some statistical parameters may include diagnostic information on technical state of rail vehicle's suspension. The comparison of simulation and experiment results depicts, that in a few examples, changes of parameters differ highly, in case of simulation, from experimental results. This occurred for the loss of damper of secondary suspension. It may be concluded that changes correspond only for kurtosis (vertical direction, v = 100 km/h, lateral direction, v = 80 km/h).

The changes of acceleration signal caused reduction of stiffness in primary suspension are particularly apparent if coefficient of variation and kurtosis are considered. For higher speed (v = 80 km/h), also variation and signal energy depict suspension malfunctions.

The differences between simulation and experiment comes from simplifications of rail and vehicles model, as well as from character of experimental signals. Nevertheless, simulation results are qualitatively well correlated with experimental results. The simulation software is useful for predicting dynamic responses in case of detecting faults in suspension.

It should be noted, that among presented parameters, there is no one, that can be used separately for assessing state of suspension. The monitoring procedure should utilize a set of parameters.

The obtained results will lead to final formulation on monitoring procedure.

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