22nd International Conference
ENGINEERING MECHANICS 2016
Svratka, Czech Republic, 9 – 12 May 2016

FAILURES OF RAILWAY VEHICLES MEASURABLE ON TRACK

J. Vágner*, J. Zelenka**, A. Hába***, M. Kohout*****, P. Havlíček*****

Abstract: *This paper describes system for diagnostics of passing vehicles with help of measurements carried out at the track. There are the signals of vibration measured on rail foot and noise signals measured near to underside of vehicle. Further failures which could be measured by this method and estimation of their dominant frequencies are described too. The system has been tested on vehicles in metro and several methods of evaluation have been proposed. Signals are assessed in the time domain and in the frequency domain. Evaluation of results is carried out using neural networks.*

Keywords: Railway, Metro, Vibrodiagnostics, Noise, Neural network.

1. Introduction

This paper introduces possibilities of failures detection of running vehicles with help of measurement carried out at the track. The paper also describes system for diagnostics of passing vehicles, which is actually developed and tested in conditions of Prague metro. The detection of selected railway vehicle failures with help of vibration and noise measurement at the stationary part of infrastructure is the aim of this diagnostic system.

2. Description of diagnostic system

The diagnostic system has been created to placing directly in metro tunnel therefore it has been constructed as dustproof, moisture and water resistant. Low power consumption, appropriate efficiency and related low heat loss of all devices has been another requirements. For carried out measurements, we used available laboratory measuring technology, commercial utilization would have required full industrial conception of that system. The basic requirement, which results from the first measurement, performs 8 acceleration or noise sensors. We usually use 2 microphones and 6 acceleration sensors. Synchronization of trainset position with the recorded signals is at high importance to right assignment of the failures relate to each carriages, bogies or axles. However the right identification of the trainset has equally importance. For those purposes, the optical gates and automatic trainset identification by WiFi connection has been used. The issues of measured data transferring have been the next solution area. With respect to interference and cable length there is not any possibility to use a metallic connection in these conditions. Therefore the data transferring has been implemented through optical fibre cable.

3. Placement of sensors in the track

We carried out a lot of measuring campaigns in 2013-2015 which was utilized for optimization of sensors placement. For obtaining suitable data to assessment, one sensor has to be placed on each rail at least and one microphone has to be placed between rails at least. However these sensors have been doubled to

* Ing. Jakub Vágner, Ph.D.: Jan Perner Transport Faculty, University of Pardubice, Studentská 95; 532 10, Pardubice; CZ, jakub.vagner@upce.cz

** doc. Ing. Jaromír Zelenka, CSc.: Jan Perner Transport Faculty, University of Pardubice, Nádražní 547; 560 02, Česká Třebová; CZ, jaromir.zelenka@upce.cz

*** Ing. Aleš Hába, Ph.D.: Jan Perner Transport Faculty, University of Pardubice, Nádražní 547; 560 02, Česká Třebová; CZ, ales.haba@upce.cz

**** Ing. Martin Kohout, Ph.D.: Jan Perner Transport Faculty, University of Pardubice, Nádražní 547; 560 02, Česká Třebová; CZ, martin.kohout@upce.cz

***** Ing. Petr Havlíček: The Prague Public Transit Co., Prague, Czech Repulic, petr.havlicek@student.upce.cz

increasing of system reliability. Two optical gates have been used for detection of passing wheelset. The gates also enable identification of trainset speed. A typical sensor placing is shown in fig. 1. Four acceleration sensors ($z_1 \div z_4$) are situated on the rail foot in the two track crosssections appropriate to optical gates (G_A and G_B) localization. Acceleration sensor z_5 is situated on the rail foot above the fixing to a sleeper and acceleration sensor z_6 is situated on the concrete base (floor) of a tunnel. Microphones were previously situated on the tunnel lining, later they were placed only between rails.

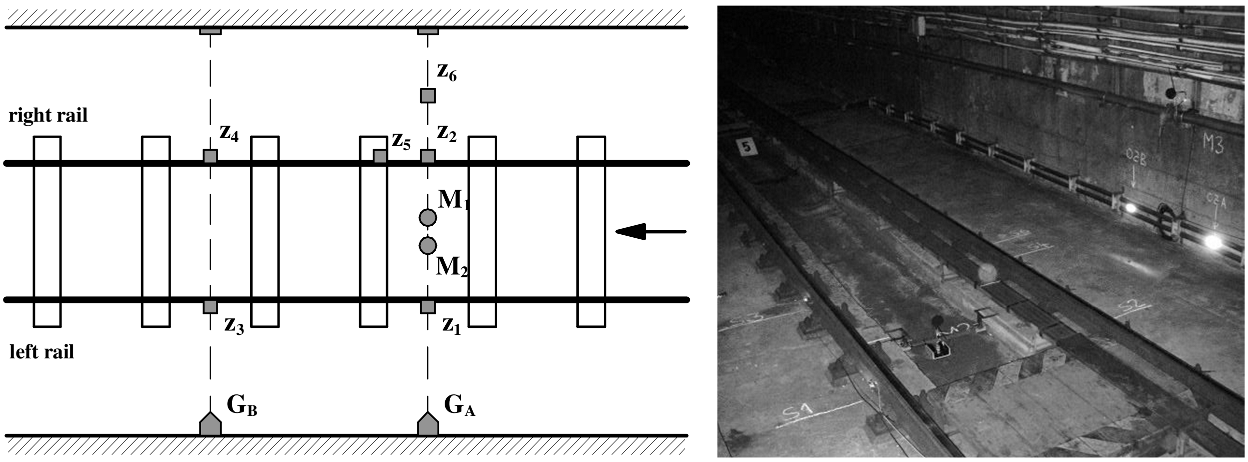

Fig. 1: Sensors placement in the track.

4. Measurable failures

At the fixed track part, it is possible to detect only the vehicles failure which shows sufficient and definite response in vibration and noise signals. With help of vibration signals we are able to detect especially failures in bogie or in mechanical part of drive. Noise signals can be used especially for detection the failures which generate such sufficient acoustic response that can be separated from the ambient noise. Searching of characteristic symptoms of appropriate failures and their quantification is the main aim of signal analyses. The evaluation of the signals has been carried out in time and frequency domain.

4.1. Wheelset failures

We can suppose several types of failure of wheelset which can create dynamical response to the track. These symptoms can be identified as a failure of wheel tread (material failure or flat caused by wheel slip) or unbalanced wheel or wheelset. If a failure occurs on the wheel tread only in one case, the dominant frequency is:

$$f_{\mathrm{W}} = \frac{1}{\pi \cdot D_{\mathrm{W}}} \cdot v, \tag{1}$$

where D_{W} is wheelset diameter and v is vehicle speed. If the wheel tread (or whole wheelset) contains more than one failure then these failures are detected only by increased dynamical response to the track.

4.2. Axle bearing failures

Failures of axle bearings can have various character and these failures can be idetifyied in frequency domain. The response appears in signals of vibration as well as noise. In usual case we can identify these failure frequences (relate to failure type): failure frequency of inner bearing ring f_{BPBI} (2), failure frequency of bearing cage f_{FT} (3), failure frequency of outer bearing ring f_{BPFO} (4), failure frequency of bearing elements f_{BSF} (5).

$$f_{\mathrm{BPBI}} = \frac{n}{2} f_{\mathrm{W}} \left(1 + \frac{d_0}{d_{\mathrm{s}}} \cos\alpha\right) \tag{2}$$

$$f_{\mathrm{FT}} = \frac{1}{2} f_{\mathrm{W}} \left(1 - \frac{d_0}{d_{\mathrm{s}}} \cos\alpha\right) \tag{3}$$

$$f_{\mathrm{BPFO}} = \frac{n}{2} f_{\mathrm{W}} \left(1 - \frac{d_0}{d_{\mathrm{s}}} \cos\alpha\right) \tag{4}$$

$$f_{\mathrm{BSF}} = f_W \frac{d_{\mathrm{s}}}{2d_0}\left(1 - \frac{d_0}{d_{\mathrm{s}}}\cos\alpha\right)^2 \quad (5)$$

where d_{s} is pitch diameter of bearing elements, d_0 is diameter of bearing element, α is connection angle of bearing elements and n is number of bearing elements.

However the equations mentioned above can be used only in optimal conditions (optimal placing of sensor) and in these application usability has not been demonstrated yet. Result frequencies can be modulated by frequency of wheelset revolutions f_{W} (2) what can show also wheelset failure (misalignment or run-out).

4.3. Wheelset drive failures

A significant response in vibration and noise signals is caused by mechanical part of traction – gearbox. This so called tooth frequency is dominant in this case. It appears due to contact of the teeth of both wheels during its rotation (6).

$$f_{\mathrm{T}} = t_1 \cdot f_{\mathrm{TM}} = t_2 \cdot f_{\mathrm{W}} \quad (6)$$

where t_1 and t_2 are numbers of teeth of both gear wheels. In frequency spectrum we can also identify tooth harmonics $k \cdot f_{\mathrm{T}}$ what can show toothed wheel worn on their contact (evolvent) surface. Some frequencies, which develop by modulation of tooth frequency ($f_{\mathrm{T}} + f_{\mathrm{W}}$; $f_{\mathrm{T}} \pm f_{\mathrm{TM}}$) can identify misalignment of pitch circles of toothed wheels relate to rotation axle or failure of gearbox bearings (f_{W} is the rotational frequency of wheelset and f_{TM} rotational frequency of traction motor.

5. Results example

The fig. 2 and 3 present comparison of two spectrograms of passing of different trainsets (trainset No. 122 and 137).

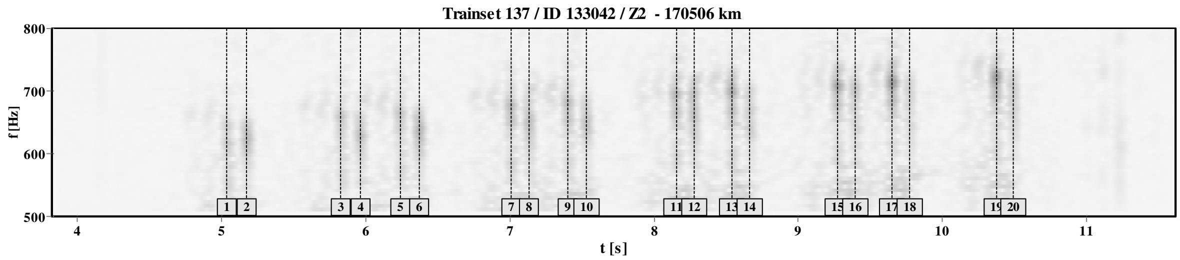

Fig. 2: Spectrogram of passing of trainset No. 137.

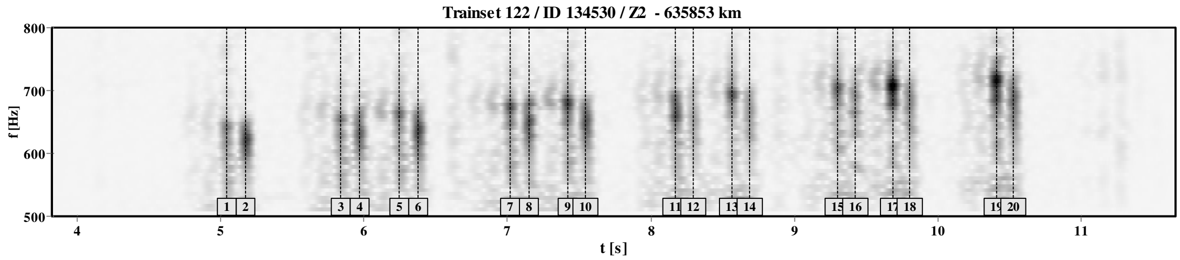

Fig. 3: Spectrogram of passing of trainset No. 122.

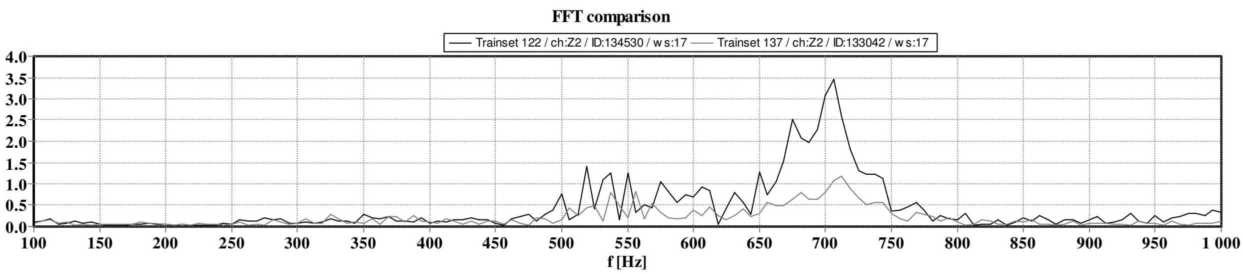

Fig. 4: Comparison of FFT spectrums for passing of 17th trainset axle.

The spectrograms of acceleration signal (sensor z_2) perform responses of gearboxes of all axles of the trainsets. There is lower response in the fig. 2 relate to fig. 3. The fig. 4 shows comparison of FFT spectrums only for 17th passing axle of each trainset. A difference between spectrums is clear especially in area of axle gearbox tooth frequency.

6. Conclusions

Results of evaluation of thousands passing show that the responses are possible to detect and frequency analysis with utilisation of neural network is the best way. Our diagnostic system is now able, using acceleration signals, to distinguish each trainset. For the correct behaviour, several trainset passing have to be measured with defined failure for learning and training of neural network to this failure symptom. To monitoring of failure development, it is necessary to carry out the measurement for a long time in defined time periods with an operation and maintenance data collection together. These activities will be solved in next stage of our project. The creation of the complete system for detection failures of passing vehicles according fig. 5 is our main aim.

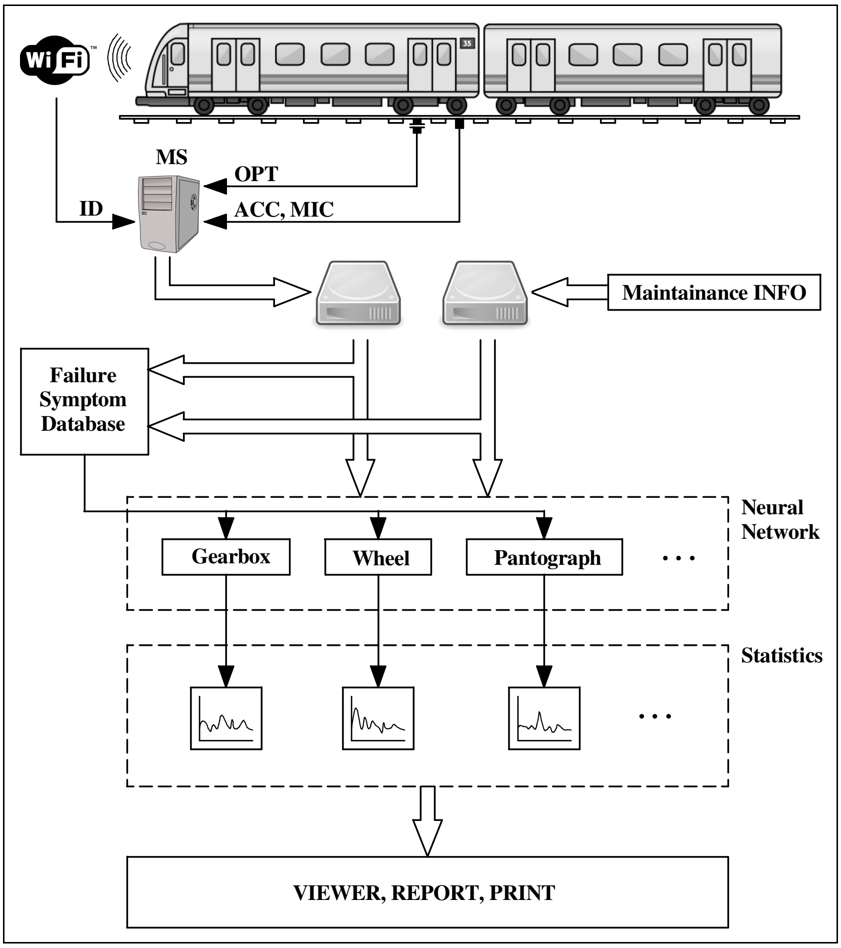

Fig. 5: Block diagram of diagnostic system for detection failures of passing vehicles.

Acknowledgement

This paper was supported by Technological Agency of Czech republic within the project No. TE 01020038.

References

VÁGNER, J., ZELENKA, J., HÁBA, A., KOHOUT, M., HAVLÍČEK, P. Stationary device for vibrodiagnostics of passing vehicle. In *Vibroengineering PROCEDIA Volume 6*. Kaunas : JVE International, 2015, p. 98-103. ISSN 2345-0533.