CONDITION MONITORING OF RAILWAY SHOCK ABSORBERS

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Summary

The paper presents the study on condition monitoring system of railway shock absorbers. The anti-yaw dampers have been chosen to apply the condition monitoring system. The application of condition monitoring system can increase safety of the train as well as reduce maintenance, service time and idle costs of the trains. The backpropagation neural network has been chosen for the decision making system.

Keywords: shock absorbers, condition monitoring, neural networks

MONITOROWANIE STANU AMORTYZATORÓW KOLEJOWYCH

Streszczenie

Przedstawiono prace nad systemem monitoro-wania amortyzatorów kolejowych. Jedne z amorty-zatorów są szczególnie odpowiedzialne za stabilność wózka podczas jazdy z dużymi prędkościami. Zastosowanie monitorowania stanu może zwiększyć bezpieczeństwo pociągu oraz zredukować czas i koszty serwisu. W systemie podejmowania decyzji została zastosowana sieć neuronowa (backpropagation).

Słowa kluczowe: amortyzatory, monitorowanie stanu, sieci neuronowe

1. INTRODUCTION

The condition monitoring of the anti-yaw dampers answers the demand of the German National Railway (Deutsche Bundesbahn DB). The anti-yaw dampers are responsible for controlling the yaw movement of the bogie. Poorly controlled yaw movement can be extremely dangerous for the train and it could cause derailment. Condition monitoring system can increase safety, as the driver would be informed all the time about the state of the anti-yaw dampers.

Without the condition monitoring system the shock absorbers are checked off the train on the mileage basis. During the checking the train remains out of the track, which generates idle costs. The condition monitoring system would reduce maintenance and service costs of the trains, because the system will point the dampers which have to be replaced.

The train is excited by sources of vibrations related to the movement along the track. Some of the sources have random character, they are for example related to the condition of the track or the wheel profile. There are also periodical excitations, for example the *hunting* movement. The *hunting* movement is described in wide range of papers [1]. The *hunting* motion is related with the movement of the wheel-set along the track. One can imagine two cones, connected with their bases, rolling along the parallel track; the irregularity of the track could cause that one of the wheels, for example the left, rolls at the part with smaller diameter, while the right wheel rolls on bigger diameter. The wheelset turns left until the *flange* hits the head of the rail, and the wheelset turns right, until the flange hits the rail again. The *wavelength* of the hunting motion is related to the geometrical and physical properties of the wheel-set and rails (radius of wheels, distance between the rails, wheels conicity, friction coefficient etc.).

The *hunting* motion is partially reduced by primary suspension. But with *anti-yaw* dampers, the train can drive at higher velocities.

The I.C.E. II trains are equipped with two anti-yaw dampers on each side of the bogie. This shows the importance of those shock absorbers. The double dampers provide higher value of stiffness and it additionally protects from the damper's failure.

2. BEHAVIOUR OF THE DAMPERS

The shock absorbers are complicated devices, which are used to dissipate the energy of the movement into heat on the way of flow of the oil, which is induced by the relative motion of the piston and the cylinder.

The oil flows through the system of orifices and valves, which are shaping up the damper's characteristic. The KONI railway shock absorbers have specific operation principle. In railway applications, the damping force should be symmetrical both in extension and in compression strokes (unlike the automotive, where characteristic is not symmetrical). To ensure such behaviour, the oil flows always in the same direction through the damping valves, while the generated pressure acts on equal surfaces.

The performance of the shock absorbers are presented on the characteristics: *force vs. velocity* graphs. The methods of obtaining the graphs are the subject of standards (eg. PN-K-88203:1996, NF F 01-411:1995 or the draft of the European standard prEN13802). The standards are describing methods of measurement and calculations of the characteristics.

The characteristic is measured in laboratory condition, where the shock absorbers are placed on testing machine. Then the sinusoidal movement, with fixed amplitude (it is also the subject of the standard, for railway dampers it is 25mm), but with various frequencies is applied to the dampers. Afterwards the *force vs. displacement* graphs are prepared. From that data the maximal velocity and maximal force are calculated. These maximal values of velocity and force are used to prepare the *force vs. velocity* graphs.

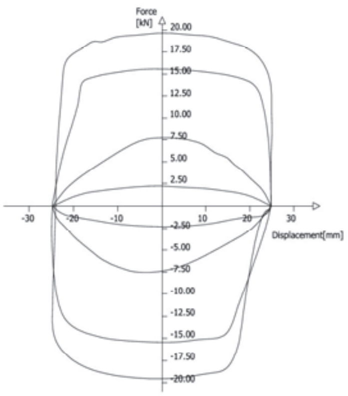


Figure 1: *Force vs. displacement* graph

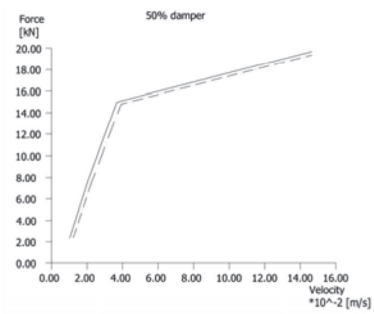


Figure 2: *Force vs. velocity* graph (dash-dotted line – compression stroke)

Figures 1 and 2 are presenting examples of characteristics: *force vs. displacement* and *force vs. velocity* graphs respectively.

3. STUDIES ON CONDITION MONITORING SYSTEM

The initial studies on the anti-yaw dampers monitoring system has been started by Kars and Wyes in 1998 [2]. The economical profitability has been calculated.

This paper proposes the algorithm which is able to distinguish the dampers with different properties. The algorithm can be applied on-line obtaining the necessary data during running of the train.

To obtain the information about the performance of the shock absorbers, they have been equipped with strain gauges attached to the piston rods (see figure 3).

Figure 3: Strain gage attached to the piston rod (under metal shield)

The strain has been equipped with a preamplifier and calibrated to measure the force acting on the piston rods.

To measure the performance of the dampers, it was necessary to measure displacement of the piston against the cylinder. For this purpose wire draw sensors has been used. The set up is presented on the figure 4.

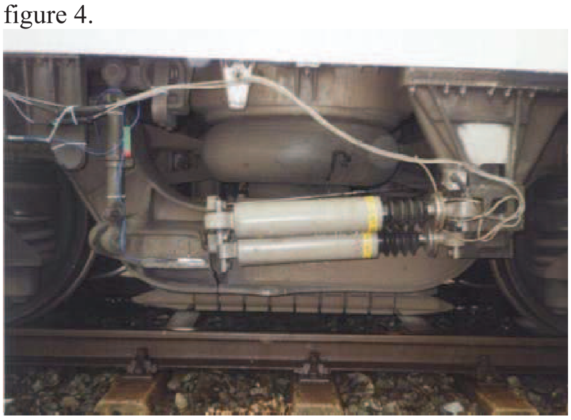


Figure 4: View of the dampers on the I.C.E. II train with attached sensors and cables

The results of train measurement have been used to obtain the track profiles. Then the track profile has been replayed in the laboratory on the SERVOTEST testing machine. This is a very powerful tool for testing the algorithms, as the damper can be tested on conditions very similar to real track.

The dampers with simulated failures have been tested using *replay* of the previously recorded track profiles. The tests have shown the different shape of the *force vs. velocity* graphs. The points on the force–velocity plane form different shapes depending on type of dampers' failures. This property has been used in design of the condition monitoring system.

4. DECISION MAKING SYSTEM

The decision making system is based on the image recognition principles. The *force vs. velocity* graphs, prepared out of measured signals, are presented in table 1. This table also contains description of the tested failures (seven cases).

4.1. Data preparation

The data preparation, to obtain the sort of *black and white* images, consisted on the following steps:

- Data recording: force and velocity signals measured in the laboratory.
- Filtering using moving average.
- Reduction of sampling rate.
- Splitting the recorded signals into shorter sections.
- Assignment of the points into grids, prepared on the force-velocity plane (force range: ±5[kN], velocity range: ±30[mm/s] – more than 90% of time, the dampers are working in this range).
- Counting the points occurring in each grids and calculating the threshold value, to obtain around 16% black grids on 20x12 *black and* white graphics.

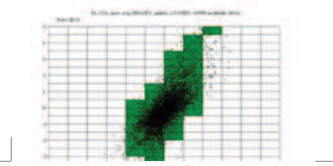
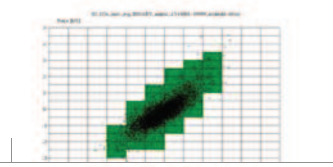
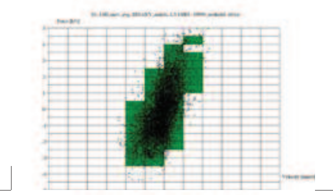
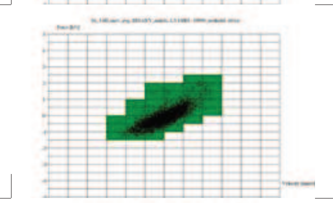
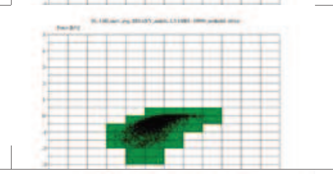
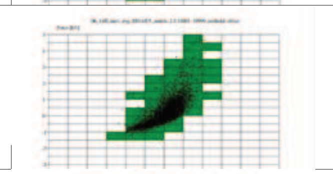
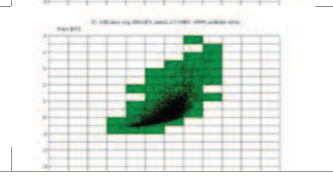
4.2. Design of decision making system

Most of the image recognition systems are working on the basis of neural network (for example optical character recognition systems – OCR). The neural networks are powerful tools used in wide range of applications (power engineering, machine tools etc.) also in condition monitoring systems.

The neural networks have been also used for diagnostic system of shock absorbers [3], but the dampers have been tested on a special testing rig. The system proposed in this paper can be implemented on the train.

The neural networks principles of operation are well described in many papers.

Table 1:
Force vs. velocity graphs, created *black and white* images created, in relation to the dampers with simulated failures

#01		100% damper Bin 1 [1,0,0,0,0]
#02		50% damper Bin 2 [0,1,0,0,0]
#03		Damper with smaller than standard constant hole Bin 3 [0,0,1,0,0]
#04		Damper with bigger than standard constant hole Bin 2 [0,1,0,0,0]
#05		Damper working in compression Bin 4 [0,0,0,1,0]
#06		Leaky non-return foot valve, h=0.09mm Bin 2 [0,1,0,0,0]
#07		Leaky non-return foot valve, h=0.14mm Bin 5 [0,0,0,0,1]

In this study, the *backpropagation* network has been used. This type of network is frequently used in image recognition systems.

The network has been built using one hidden layers of neurons; 240 neurons in input layer (number of grids in the *graphics*), 25 neurons in hidden layer and 5 neurons in output layer. The sigmoidal activation function has been used; this means the output values are in the range (0,1).

The targets are five elements vectors also presented in table 1.

The dampers with the failures have been divided into 5 bins, depending how serious is the influence of the failures on the dampers' performance:

- Bin 1: dampers are working properly; no hazard to the train.
- Bin 2: dampers are working worse than specified. The train is still safe, but the

dampers should be replaced during next servicing.

- Bin 3: dampers are too hard, the train is safe, but the dampers should be replaced (see Bin 2).
- Bin 4 and Bin 5: dampers are not working properly, they should be replaced at first opportunity.

The neural network has been trained using the input vectors, built from first three sections of the recorded force and velocity signals recorded during replay tests of the dampers with simulated failures.

5. TESTING

The neural network has been tested using the remaining fourth section of the data coming from measurement. The results of the testing are presented in table 2.

Table 2: Results of testing the neural network.

Damper 's No:	Result (outputs of the neural network)	Resem-blance to bins:
#01	[**0.99**,0.01,0.01,0.01,0.00]	Bin 1
#02	[0.00,**0.95**,0.00,0.00,0.01]	Bin 2
#03	[0.01,0.00,**0.99**,0.00,0.00]	Bin 3
#04	[0.01,**0.99**,0.00,0.00,0.00]	Bin 2
#05	[0.00,0.01,0.02,**0.97**,0.00]	Bin 4
#06	[0.00,**0.98**,0.00,0.00,0.01]	Bin 2
#07	[0.00,0.01,0.01,0.00,**0.97**]	Bin 5

6. FURTHER DEVELOPMENT

The paper presents the algorithm which is able to recognize the state of the shock absorbers, after analysing the data recorded during the replay of the track profile signals.

The further development should include choice of appropriate sensors, which will be used in recording the data about the performance of the shock absorbers during operation on the train.

The electronic system responsible of recording and processing the data should be developed. The electronics should be fitted on the damper together with the sensors. The electronic system should send the warning message about the condition of the shock absorber directly to the driver of the train.

7. CONCLUSIONS

The algorithm presented in the paper successfully recognizes the exposed for the testing data. The structure of the algorithm enables easy on-line implementation. The proposed system can increase the safety of the high speed trains and reduce servicing and idle costs of their maintenance.

ACKNOWLEDGEMENT

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