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IEGULDĪJUMS TAVĀ NĀKOTNĒ!

Eiropas Reģionālā attīstības fonda projekts „Optiskās šķiedras sensora pielietošanas transportlīdzekļu svara automātiskai mērīšanai kustībā: izpēte un izstrāde” Nr.2010/0280/2DP/2.1.1.1.0/10/APIA/VIAA/094

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Editors' Remarks

****

A Brief History of Gravity

by Bruce Elliot

It filled Galileo with mirth
To watch his two rocks fall to Earth.
He gladly proclaimed,
"Their rates are the same,
And quite independent of girth!"

Then Newton announced in due course
His own law of gravity's force:
"It goes, I declare,
As the inverted square
Of the distance from object to source."

But remarkably, Einstein's equation
Succeeds to describe gravitation
As spacetime that's curved,
And it's this that will serve
As the planets' unique motivation.

Yet the end of the story's not written;
By a new way of thinking we're smitten.
We twist and we turn,
Attempting to learn
The Superstring Theory of Witten!

****

Bruce Elliot ♣

This 16th volume no. 4 presents specials topics on the project **'Fiber Optic Sensor Applications for Automatic Measurement of the Weight of Vehicles in Motion: Research and Development (2010-2013)'**, which was granted by ERDF funding No. 2010/0280/2DP/2.1.1.1.0/10/APIA/VIAA/094, 19.12.2010.

Our journal policy is directed on the fundamental and applied sciences researches, which are the basement of a full-scale modelling in practice.

This edition is the continuation of our publishing activities. We hope our journal will be interesting for research community, and we are open for collaboration both in research and publishing. We hope that Journal's contributors will consider the collaboration with the Editorial Board as useful and constructive.

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I. V. Kabashkin

♣ http://www.twilightbridge.com/humor/issacnewton.htm, http://everything2.com/title/Physics+Limericks

Computer Modelling and New Technologies, 2012, vol. 16, no. 4, 7–9
Transport and Telecommunication Institute, Lomonosov 1, LV-1019, Riga, Latvia

PROJECT 'FIBER OPTIC SENSOR APPLICATIONS FOR AUTOMATIC MEASUREMENT OF THE WEIGHT OF VEHICLES IN MOTION: RESEARCH AND DEVELOPMENT'. *FOREWORD*

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The growth of the level of traffic intensity in the European Union countries, the creation of the traffic control intelligent transport systems (ITS) and problems of maintaining the quality of road surfaces have led to the creation of sensor networks for weighing road vehicles. Freight logistics using heavy trucks is essential overland transport type, which could reach up to 13% from total Latvian overland transportation, transporting on an average 1,9 million tons of freight (by data about freight transportation in 2007–2009 years from the Statistical Department of the Republic of Latvia). This amount of the regular transportation creates additional load on the auto road surface, especially in cases, when heavy trucks are transporting freights, which exceed the allowed weight norms. In Latvia limitations for heavy truck total weight and axle weight are regulated by Cabinet of Minister rules (Nr. 571. 3 appendix), where the 9th point says, that one axle load without double wheels is 10 tons, but according to the LETA news agency summary about this situation in Latvia at least 12000 trucks are exceeding this norm, creating the following consequences:

- Overloaded trucks every day destroy road surface, because road is designed on the base of the allowed loads. But, for example, heavy truck axle, which weighs 20 tons, makes 40 times more damage than truck with normal axle load – 10 tons. So far researches show that heavy truck, which is overloaded by 20%, makes the same damage to the road surface as 20 the same class vehicles, which are not overloaded. These problems create extra expenses for road repair works to the state budget.
- Overloaded trucks make danger to the traffic safety, especially in bad weather conditions, when rain or snow create extra risk to the vehicle to slide down of the road and overturn, in this way creating danger also to the other participants of the traffic.
- Overloaded trucks distort market competition, because forwarders, who notice norms, transport light freights and in this way earn lesser.

The main problem, why on the state roads regularly drive overloaded heavy trucks, there is insufficient control by the responsible institution and relatively expensive techniques for transport freight control. Presently in Latvia Auto Transportation Inspection mobile crews with portable axle weighting systems are responsible for these control functions. But the main disadvantages of these weighting systems are as follows:

- Time and personal resource big consumption – vehicle inspection realization on the road is available only for one person, who is legally authorized to stop a vehicle for check. The second person is working with weighting system, helping driver to fix a vehicle on the weight (2 platforms) by 2 vehicle axles. After inspection violation act is officially registered, the whole process has taken 10–30 minutes. During that time a lot of other violators are not being punished and are continuing driving.
- Low precision, because for absolutely precise weighting it is important to install weighting platform on the flat surface, what is almost not possible, excluding cases, when special weighting fields or weighting paths are built. At the moment there are only 2 such paths in Latvia.
- Relatively short lifetime (4–5 years).

That's why in other countries weighting stations that consist from 2 main elements are in use:

1. Overloaded vehicle selection by weighting it in motion on the road on habitual speed.
2. Low speed or static weighting with high accuracy.

To weight a vehicle in motion on the road with speed up to 120 km/h, usually piezo metric or quartz sensors are used, installed inside the road surface, but there are 2 main problems with these weighting systems:

- In long-term use they are destroyed – because sensors are installed in unbendable metal body, and when road surface becomes damaged, sensor's geometrical shape is changing, and as a result the whole sensor is damaged.
- High expenses, because sensor is expensive. Use of whole weighting system requires big expenses.

In Latvia the above-mentioned piezo metric and quartz sensors were not used for truck inspection because of the big expenses. Keeping in mind the above-mentioned negative consequences, which derive from the overloaded trucks, as well as the mentioned problems, connected to the vehicle control using portable axle weighting systems and piezo metric or quartz sensors, we as a research object promote to find alternative technical solution to the existing devices for truck weighting systems, developing new and unique product, which would be more convenient in use, more precise and cheaper.

It is the background of the ERDF funding project „Fiber Optic Sensor Applications for Automatic Measurement of the Weight of Vehicles in Motion: Research and Development", fulfilled by the researchers of Transport and Telecommunication Institute (Riga, Latvia) in 2010–2013. In the framework of the project we will offer existing products (portable axle weights, piezo metric and quartz sensors) replace with optical fibre sensors.

Optical sensor use in the vehicle weighting system has the following advantages:

- They are not sensitive to the electromagnetic field, which means that they could be installed in places where compact metal constructions are, and they do not need lighting safety system.
- Comparison to the piezo metric and quartz sensors, which lifetime is 4–5 years, new product – optical sensors lifetime is practically not limited (approx. 20 years).
- Sensors and their installation are relatively cheap because of their small diameter and simplicity.
- Weight radar with optical cable in difference with portable axle weights is stationary and working automatically, and personal presence is not needed on the installation place. Automatic weighting has several advantages:
  - weighting does not need personnel;
  - vehicles are weighted without stop;
  - all vehicles are weighted.
  - vehicles are not stopped on the roadside thus causing danger to other traffic participants.
- Signal transfer does not require electricity, in that way they might be installed 20 km away from the electricity source. Light signal by the optical cable is transferred from light source, which is connected to electricity. Light signal transmission distance is not limited. When vehicle drives up on the sensor, light flow intensity changes. These changes are converted into electrical signal by optical-electronic interface.

Optical fibre sensors are planned to install into road base, which automatically will fix a weight of the vehicle and if allowed mass is exceeded, weighting system will fix also certain vehicle state number or even a driver's picture and will send it to the central computer for further data processing and fine application for violation. Existing quartz and piezo metric sensors are not used for fine application. The result of the project might be used also in other spheres:

- on the roads – determination of the vehicle speed, vehicle classification and counting, traffic jam determination and traffic light control;
- on the railway – switch control, weighting and damaged wheel detection;
- in construction – building deformation determination, for example, in bridges;
- as sensors in weight control devices replacing classical tensometric sensors, because piezo and quartz sensors might be used only for moving object weighting.

During the project different kinds of activities have passed: laboratory research of fibre optic sensors (FOS) properties, road measurements of trucks weight, theoretical and numerical modelling of rolling wheel dynamics, digital signal processing algorithms programming, and prototype of weight measurement station devices design. We are grateful to all project team members for their attempts in research work as well as the partners – the company SENSORLINE GmbH, fibre optic sensors producer from Germany. Some preliminary results of this investigation are presented in this issue.

Acknowledgements

This research was granted by ERDF funding project "*Fiber Optic Sensor Applications for Automatic Measurement of the Weight of Vehicles in Motion: Research and Development* (2010–2013)", No. 2010/0280/2DP/2.1.1.1.0/10/APIA/VIAA/094, 19.12.2010.

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IMPACT OF THE EXTERNAL FACTORS ON THE MEASUREMENT OF WEIGHT-IN-MOTION BY FIBRE OPTIC SENSOR

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The results of application of fibre-optic sensors for measuring the weight of moving vehicles (weight-in-motion – WIM) are discussed in the present study. The different factors affect the measurement accuracy of fibre-optic sensors: features installed in the roadbed, and the nonlinearity and the lag effect of the sensor, the temperature effect. The results of laboratory and field measurements using a fibre-optic sensor are presented as well as a load and inertial characteristics and their approximations obtained for fibre-optic sensor under the impact of various external factors (protective cover, temperature, contact area, and especially installation). It has been found that the final calibration of the sensor can be done individually only after it is installed in the pavement. We discuss the algorithms for linearization, methods of temperature and dynamic oscillations compensation of fibre-optic sensor's data for its use in the measurement of weight-in-motion.

Keywords: transport telematics, weight-in-motion (WIM), fibre optic sensors (FOS), sensor's sensitivity, measurement, calibration

1. Introduction

Sensor networks for weighing road vehicles are the tools for the problems of maintaining the quality of road surfaces solution in conditions of growth of traffic intensity in the European Union countries and creation of the traffic control intelligent transport systems (ITS). Nowadays, the use of fibre-optic sensors (FOS), based on the change of the parameters of the optical signal from optical fibre strain under the weight of passing transport [1], takes an especial popularity in the problems of transport telematics. These sensors are relatively durable and inexpensive to manufacture and operate. However, due to the low accuracy of measurement of weight (especially weight of a moving object), and high dependence on weather conditions, they are used mainly as a vehicle's motion detectors only.

Last trends on WIM issues indicate that FOS sensors are based on two main principles: Bragg grating (the change of diffraction in a channel under deformations) [2] and change under deformations of the fibre optical properties (transparency, frequency, phase, polarization) [3]. The change of transparency (the intensity of the light signal) of SENSORLINE experimental sensors [4], as basic operating principle, is considered in this study.

Most popular are the multi-sensor systems (MS-WIM) [5], where the accuracy of measurements is obtained by statistical processing of 6–20 or more sensors, situated in sequence into the pavement at some distance to each other. Obtaining the measurement errors of < 5% on speed of 50–100 km/h this approach takes the expenses, compatible with the bending plates and needs the reconstruction of roadside surface. The aim of the present study is to obtain the measurement errors of 2–10% without multiplying of sensors.

2. Measurement Principles of the FOS Sensor

The fibre optic force sensor is a cable consisting of a photoconductive polymer fibres coated with a thin light-reflective layer (Fig. 1). A light conductor is created in this way, from which the light cannot escape. If you direct a beam of light to one end of the cable, it will come out from the other end, and in this case the cable can be twisted in any manner. In order to measure the force acting on the cable, the amplitude technology is more appropriated for measurement, when measures the optical path intensity, which changes while pushing on the light conductor along its points.

At these points the deflection of a light conductor and reflective coating occurs, that is why the conditions of light reflection inside are changed, and some of it escapes. The greater the load – the less light comes from the second end of the light conductor. Therefore the sensor has the unusual characteristic for personnel, familiar with strain gauges: the greater the load – the lower the output is. Apart from the fact that it is reversed and in addition to this it is non-linear.

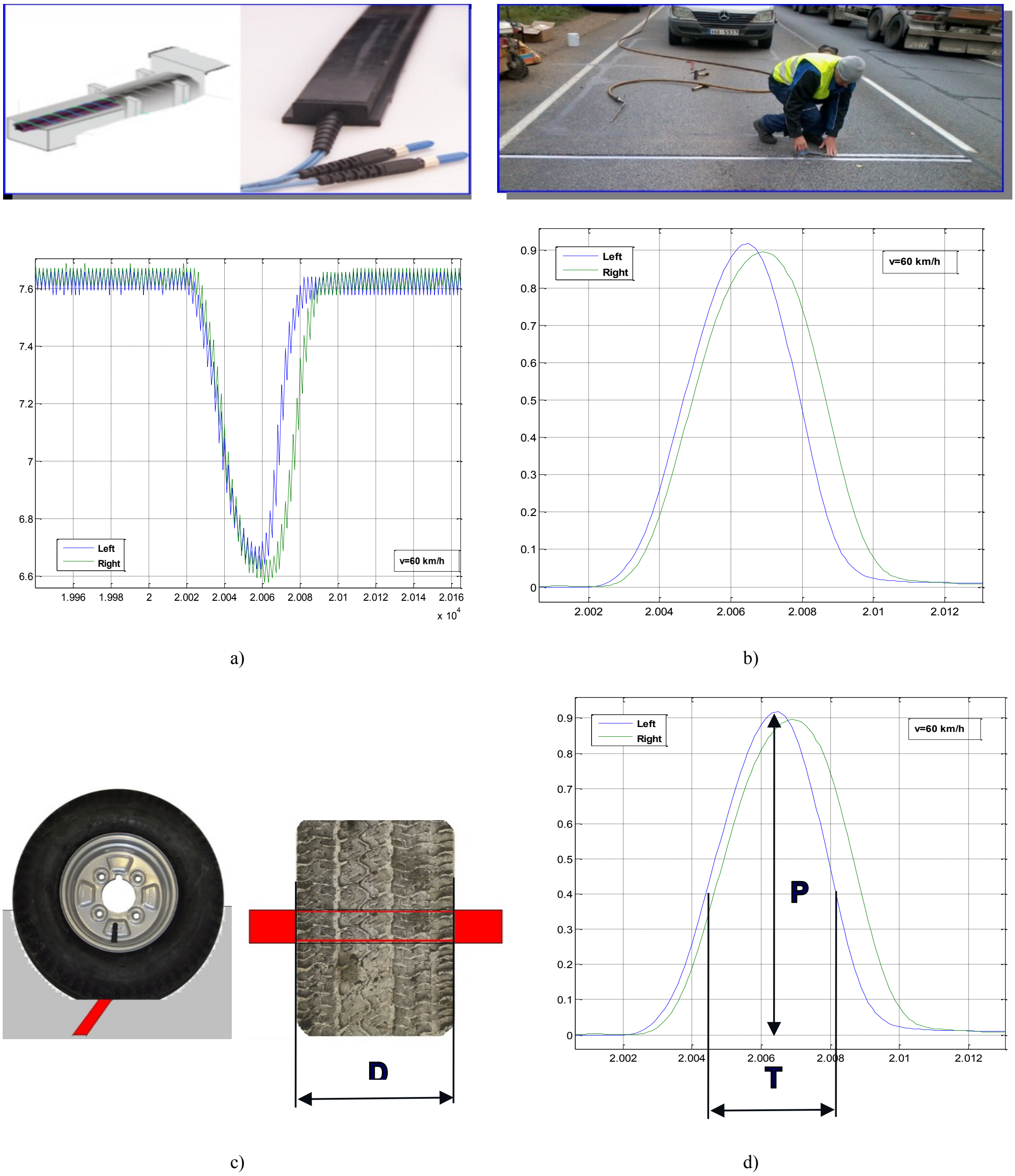


Figure 1. Location and waveform of the SENSORLINE PUR fiber optic sensor [5], (a) Voltage, (b) Visibility losses, (c) sensor's position against the wheel and wheel's footprint, (d) measured parameters for weight calculations

Let to avoid the inaccuracy of zero load level we need to exclude the high frequency components from the voltage signal at the output of the sensor's transducer by filtering as well as to recalculate the voltage signal $U(t)$ (Fig. 1(a)) into the relative visibility losses signal $V(t)$ (Fig. 1(b)), directly related to the weight pressure on the FOS surface, by the transformation (1):

$$V(t) = \frac{U_0 - U(t)}{U_0}, \tag{1}$$

where U_0 is the voltage of sensor's output with zero load. The signal transformation to the relative visibility losses signal $V(t)$ gives the possibility to compare signals for different measurements in different conditions.

Fibre optic load-measuring cables are placed in gap across the road and are filled with resilient rubber (Fig. 1).The gap width is 30 mm. Since the sensor width is smaller than the tyre footprint on the surface, the sensor takes only part of the weight axis. Two methods are used in the existing systems to calculate the total weight of the axle [2, 3]: the Basic Method and the Area Method. The following formula is used to calculate the total weight of the axis using the Basic Method:

$$W_{ha} = A_t \cdot P_t \,, \tag{2}$$

where W_{ha} – weight on half-axle, A_t – area of the tyre footprint, $P_t \sim V(t)$ – air pressure inside the tyre and, according to Newton's 3rd law, it is proportional to the axle weight.

As we can see the exact values of the formula factors are unknown. The area of the tyre footprint is calculated roughly by the length of the output voltage impulse, which, in its turn, depends on the vehicle speed. The Area Method uses the assumption that the area under the recorded impulse curve line, in other words – the integral, characterizes the load on the axle. To calculate the integral, the curve line is approximated by the trapezoid. In this case the smaller the integral – the greater the load. This method does not require knowing the tyre pressure, but it requires the time-consuming on-site calibration. Also, it has to be kept in mind that the time of the tyre passing on the sensor is too small to get an electrical signal of high quality for its further mathematical processing. We use the Area method for footprint area definition in (2), but the pressure is measured from the signal amplitude.

3. Experimental Vehicle's Axle's Weight Measurement in Motion by FOS

There was the set of measurement experiments with the roadside FOS sensors on April, 2012. Loaded truck (Fig. 2) was preliminary weighed on the weighbridge with the accuracy < 1%.

Figure 2. Experimental truck "Volvo FH12" with full load 36900 kg

Table 1. Date: 20.04.2012 (Air Temperature +12°C)

Etalon axle's weight (tons):	7.296	12.619	5.509	5.641	5.844

Etalon weights of separate axles are given in the Table 1. The signals from output of FOS sensors for truck speed 70 km/h and 90 km/h are demonstrated on Figure 3. It is evident that the signals for different speed are strongly changed by amplitude and the proportion of amplitudes does not fit the axle's weights (Fig. 3).

The reason of this behaviour may be concluded in the FOS properties such as weight (pressure) distribution along the sensor's length as well as sensor's non-linearity and temperature dependence.

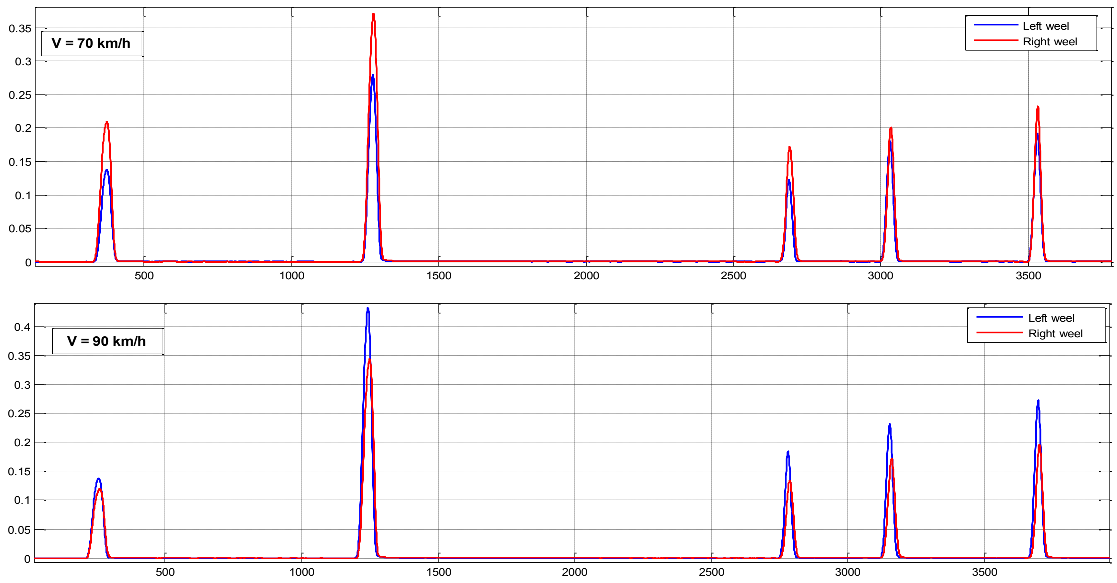


Figure 3. Examples of FOS signals of experimental truck for vehicle's speed 70 km/h and 90km/h respectively

4. Fibre Optic Sensor's Properties and Output Characteristics

Load characteristic was measured from the SENSORLINE PUR fibre optic sensor by means of a SL Transducer (optical interface) optical signal analyser has been developed by SensorLine GmbH [4].

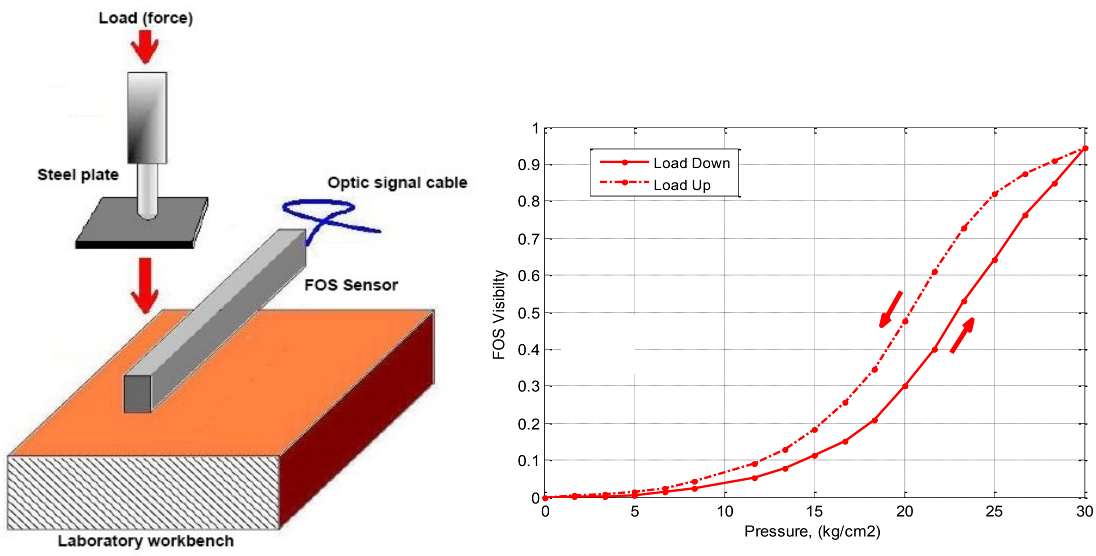


Figure 4. (a) Experimental laboratory equipment scheme and (b) Static load characteristic of FOS SENSORLINE (PUR)

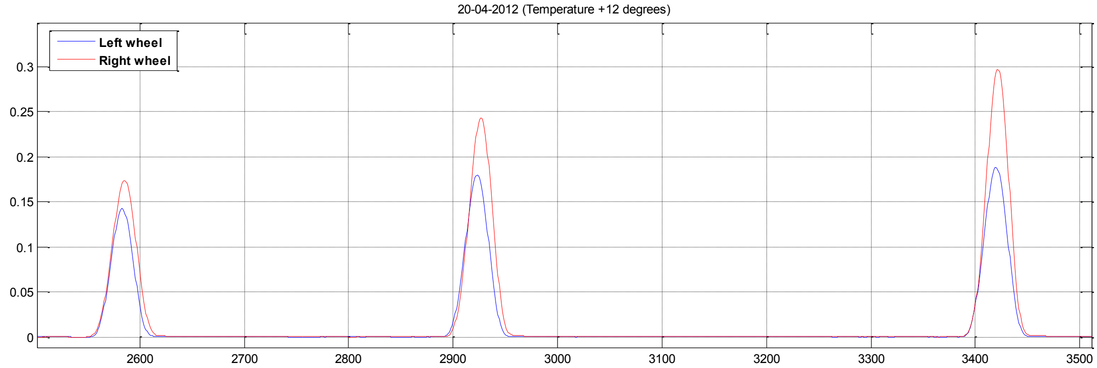
For obtaining the static load characteristics of the sensor the MTS compression machine of the Institute of Polymer Mechanics of the University of Latvia was used. Effort in the range 0–2000 kg was transmitted to the sensor through a steel plate (see Fig. 4(a)) the size of 200 mm by 200 mm at the temperature conditions of +18^{o}C. The area of application of the force to the sensor was 30 mm to 200 mm. Load curves (gradual increase of the force) and unloading (gradual decrease) of the sensor are shown on Figure 4(b).

The curves clearly demonstrate the presence of nonlinear behaviour – the so-called "hysteresis loop", or the difference between the curves "load-on" and "load-off". The reason for this is the residual deformation of rubber protective sensor housing. These curves are conveniently approximated by hyperbolic tangent function:

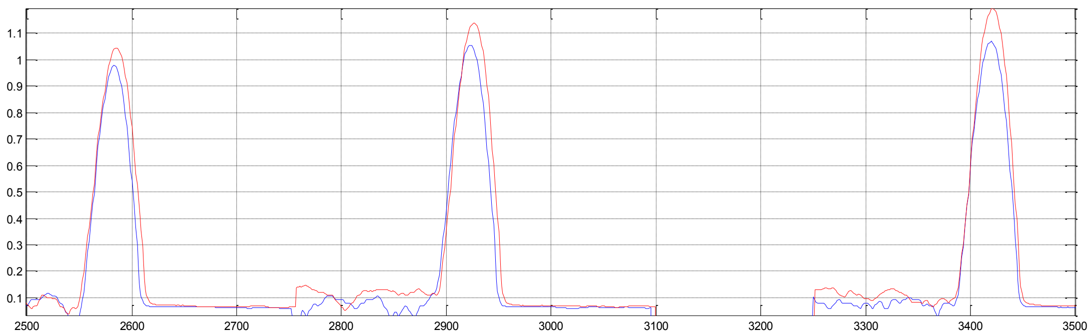
$$V(p) = a_0 + a_1 \cdot \tanh(\omega \cdot p + \varphi)\,, \tag{3}$$

where p is the pressure on the sensor's surface but a_0, a_1, ω and φ – are the parameters of approximation.

For example, "load-on" curve from the Figure 4(b) conditionally describes by the next approximation coefficients: a_0= 0.4994, a_1 = 0.5006, ω = 0.1480, φ = -3.3702, calculated by the method of least square criteria optimisation. For the local approximation is quite suitable to use cubic or quadratic approximation polynomials, defined by the criterion of least squares. An example of the signal linearization, based on the curve (Fig. 4(b)), is presented on Figure 5(b).



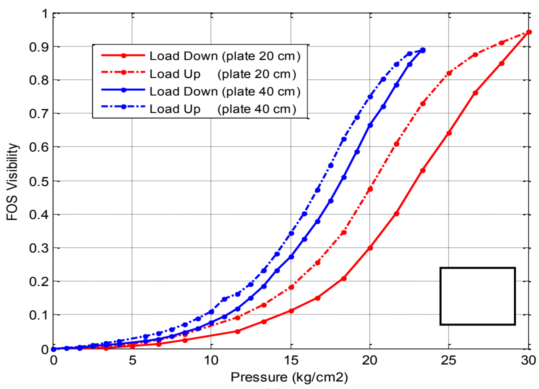
(a)



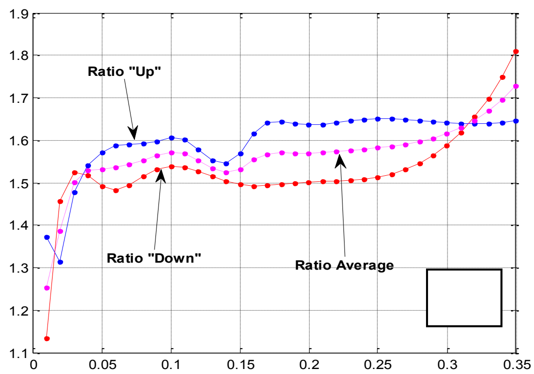
(b)

Figure 5. (a) An example of 3-axles FOS signal and (b) The same signal after linearization (pressure in kg/cm^2 on vertical axis)

Another experiment has been associated with the influence of sensor data, produced by the dual wheels. Comparison of load curves at the impact area through the steel plate with the size of 200 mm by 200 mm and 400 mm by 400 mm is shown on Figure 6(a). The impact area on the sensor is increased by 2 times, and the losses of transparency of the FOS, as can be calculated from the relative position of the curves (Fig. 6(b)), decreases approximately by $\pi/2$ times, due to the radial distribution of load along the contact surface of the steel plate and the sensor.

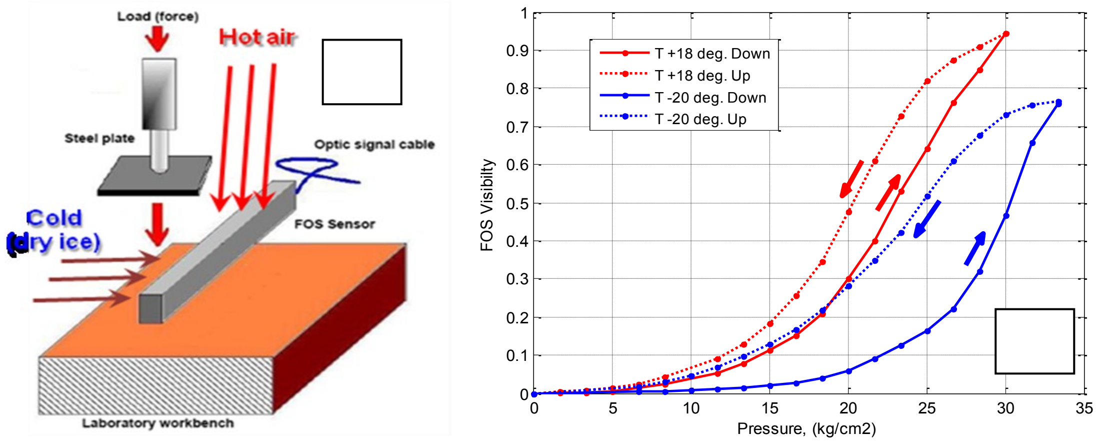


(a)



(b)

Figure 6. (a) Experimental static load characteristic of FOS with doubling of active area and (b) Ratio between two curves by the length of 200 and 400 mm respectively

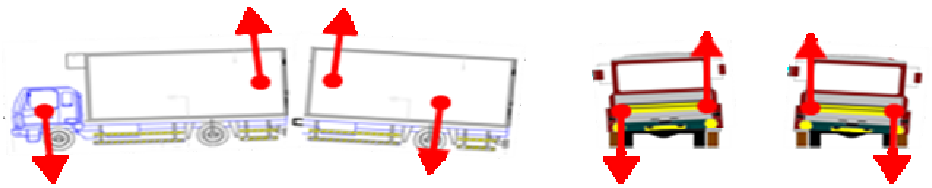


(a) (b)

Figure 7. (a) Scheme of temperature factor measurement and (b) Experimental static load characteristic of FOS with doubling of active area of wheel's footprint

In actual conditions of use the fibre optic sensor (FOS) with the protective rubber housing is built into the road surface and, therefore, affected by temperature, which changes the stiffness of rubber. An experiment determining the effect of temperature's factor is to obtain load characteristics and comparison with FOS at 18°C and after cooling in the freezer camera down to -20^{o}C. The results of these measurements are shown on Figure 7(b).

Due to changes in the cover housing rubber stiffness the measurements of pressure change up to approximately 50% and residual effects (hysteresis) increase. Consequently, it is necessary to use the temperature correction in the measuring scheme.



(a) (b)

Figure 8. (a) Longitudinal oscillations, and (b) Transversal oscillations of load on the wheels of moved vehicle

Another source of measurement errors can be dynamic oscillation of the load of each wheel due to movement (see Fig. 8). The transversal dynamic oscillations leads to different loads on each wheel in axle but not add the error to the common axle's weight measurement results. Most sufficient seems the longitudinal oscillation because it leads to additional vertical force (or decreasing of it) to both wheels in axle simultaneously.

For correction of these errors we assume that relative value of friction force, calculated by decomposition of the signal on even and odd parts [6], is dependent on footprint length and, respectively, it changes due to dynamic oscillations. From the other hand, without oscillations it is assumed to be in proportion with the amplitude of relative derivative of the signal (rate of grow).

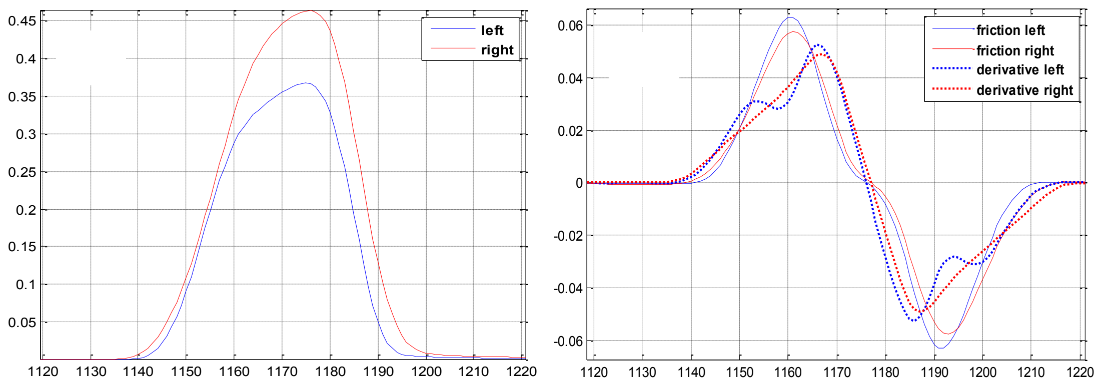


Figure 9. (a) FOS signals from one axle, and (b) relative friction and derivative components for the same signals

An example of these components of the signals is presented on Figure 9 for both left and right wheels. As it is seen from the Figure 9, the friction and derivative of weight component slightly differs to each other by the amplitude. The idea of errors correction is in the equalization of both components for each wheel in axle, when scaled friction component again adds to weight component to obtain modified signal without influence of dynamic oscillations. The results of application of proposed approach are reflected in Table 2.

Figure 10. Experimental FOS signals normalization device based on PIC-processor

A possible alternative technical solution of this problem may be a device called the FOS output normaliser, and performs the task of linearization and temperature compensation (Fig. 10). The device is protected complying with OIML R 76 and EN 45501. To communicate with a central computer for long and short-distance the normaliser has the RS-485 and RS-232 digital interfaces. The microcontroller PIC 18F25K80 with 4K RAM and 64K of permanent memory, has a clock frequency of 64 MHz.RAM, memory of device contains the information about the vehicle having no more than eight axes.

6. Results and Discussion

The accuracy of weighing the vehicle in motion depends on many factors, but the main errors in the existing systems consist of the following: non-linearity and inertia of the sensor, thermal effects, and inertial force of an oscillating vehicle.

Applying the algorithm of FOS signal processing with the approximation of nonlinear characteristics of the sensor (3) for a suitable range of temperatures, it is possible to calculate the following weights of axes (Tab. 2):

Table 2. Characteristics of the sensor

Date: 20.04.2012 (Air Temperature +12^{o}C)						
Etalon axle's weight (tons):		7.296	12.619	5.509	5.641	5.844
Speed: 10 km/h						
No	Parameter:	1st axle	2nd axle	3rd axle	4th axle	5th axle
1	Axle's weight (tons)	8.1876	13.3466	5.0245	5.5659	5.4438
	Error (%)	12.21%	5.77%	-8.79%	-1.33%	-6.84%
2	Axle's weight (tons)	7.8218	13.5065	5.1057	5.7214	6.6604
	Error (%)	7.20%	7.03%	-7.32%	1.42%	13.97%
Speed: 20 km/h						
1	Axle's weight (tons)	8.1431	13.2625	4.9336	5.6830	5.6110
	Error (%)	11.61%	5.10%	-10.44%	0.74%	3.98%
2	Axle's weight (tons)	8.3815	13.9084	4.9293	5.3014	5.2716
	Error (%)	14.87%	10.22%	-10.52%	-6.02%	-9.79%
Speed: 50 km/h						
1	Axle's weight (tons)	7.9016	12.4905	5.0221	5.2576	5.4258
	Error (%)	8.29%	-1.02%	-8.83%	-6.80%	-7.15%
2	Axle's weight (tons)	7.7431	13.3150	4.6333	5.1742	5.2767
	Error (%)	6.12%	5.52%	-15.89%	-8.28%	-9.70%
Speed: 70 km/h						
1	Axle's weight (tons)	7.8760	12.5578	5.1595	5.6120	5.6925
	Error (%)	7.95%	-0.48%	-6.34%	-0.52%	-2.59%
2	Axle's weight (tons)	7.6155	12.2707	5.0340	5.5636	5.6679
	Error (%)	4.37%	-2.75%	-8.62%	-1.38%	-3.01%
Speed: 90 km/h						
1	Axle's weight (tons)	7.1292	13.3371	5.1899	5.7197	5.8324
	Error (%)	-2.29%	5.69%	-5.79%	1.39%	-0.19%
2	Axle's weight (tons)	7.6745	13.3600	5.1701	5.6840	5.8153
	Error (%)	5.18%	5.87%	-6.15%	0.76%	-0.48%

As it can be seen from the table (Table 2), the velocity ranges from 70 km/h and above are most preferred for measurements, when the measurement errors of the load on the axle does not exceed 10%, which is consistent with the problem of pre-selection of overloaded vehicles. This level of errors has the reason due to vertical oscillations of the dynamic motion of the vehicle, whose amplitudes are smaller at higher speeds. By the properties of each individual sensor, the calibration of FOS should be conducted twice: firstly, in the laboratory (load characteristics in the temperature range from -20^{o}C to +30^{o}C), and, secondly, – after installing the sensor in the road surface with vehicles with a standard load usage.

To increase the accuracy of axes weight in the motion measurement it is necessary to select the area of data representation, where the static and dynamic components of the weight can be separated, let to be able to remove the dynamic components from the signal [2].

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SIGNAL SIMULATION FIBRE OPTIC SENSORS MEASURING WEIGHTIN MOTION IN THE BASIS OF THE DIFFERENTIAL EQUATIONS

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In the present study we are discussing the possibility of fiber optic sensor application for weighing road vehicles in motion (WIM – weight-in-motion). The various factors affecting the accuracy of fiber optic sensors measurement are considered to be: features of the installation in the roadway, the nonlinearity and inertia of the sensor, the thermal effect, the inertial force of the vibrating vehicle and the extremely short time of the load standing on the sensor. The impact of these factors on the accuracy of WIM systems were analyzed and tested by simulations and field tests. The aim of this work is to simulate the signal of fiber optic sensors in the basis of differential equations of a deformable wheel bearings, the identification of linkages with optoelectronic mechanical parameters and to find the mass of the vehicle by minimizing the discrepancy between the actual WIM-signal and the solution of the differential equation of oscillations of the wheel.

Keywords: transport telematics, vehicle detection, weight-in-motion (WIM), fibre optic sensors (FOS), stiffness of bracket and tire

1. Introduction

The results of the application of the fibre-optic sensors for measuring the weight of moving vehicles (weight in motion – WIM) are discussed in the present study. Their work is based on the change in the parameters of an optical signal from an optical fibre strain under the weight of passing vehicles [1].

High-speed WIM systems to ensure the accuracy of class B + (7) in a range of speeds from 30 km/h to 90 km/h are widely used around the world. The aim of this work is to simulate the signal of fibre optic sensors in the basis of differential equations of a deformable wheel bearings [2–6], the identification of linkages with optoelectronic mechanical parameters and to find the mass of the vehicle by minimizing the discrepancy between the actual WIM-signal and the solution of the differential equation of oscillations of the wheel. The accuracy of the weight depends on many external factors [6], the mathematical modelling of these factors are expressed in the numerical values of the coefficients and external stimuli. The impact of these factors on the accuracy of WIM systems were analysed and tested by simulations and field tests.

2. Modelling Signal Fibre-Optic Sensors

From the theory of deformable wheel bearings [2–6] that the wheel side of the road is normal and tangential distributed reaction. Complete description of the dynamics of the mass of the vehicle forms a unified system of differential equations that take into account the interaction of two masses – rotating and moving steadily. The total number of the second order differential equations is six, two for each spatial coordinate. Into account for the problem of determining the mass car all times, the drag coefficient of the road, rolling friction, etc. unreal.

Simplifying the equations of motion of a deformable wheel radius r, the mass m and the moment of inertia J under the axle load P, force F, the torque M and N of the normal reaction of the road in the x and y leads to the relations

$$m \cdot \ddot{x} = F + F_{Tp} \cdot Cos\alpha - N \cdot Sin\alpha, \tag{1}$$

$$N \cdot Cos\alpha - P + F_{Tp} \cdot Sin\alpha = 0, \tag{2}$$

$$J \cdot \ddot{\psi} = M - r \cdot F_{Tp} - N \cdot k. \tag{3}$$

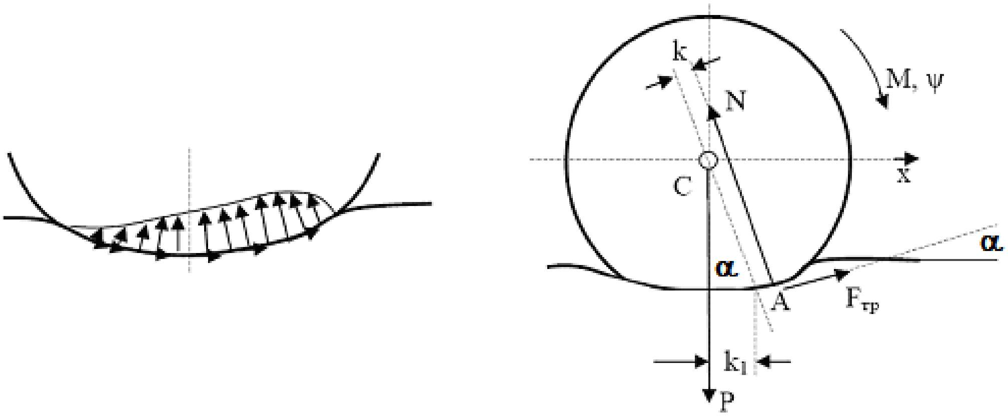

Figure 1. Wheel's forces distribution (left) and dynamics of the forces (right) [4]

Line of action of the reaction $\boldsymbol{N}$ (Fig. 1) is generally offset from the centre of the wheel so that it prevents the wheel rotation time, which is due the load. Limit offset k is called the rolling friction and displacement k_1 coefficient of resistance of the road.

If the smallness of the angle of friction forward horizontally, the approximate equations of motion take the form of wheels:

$$m\ddot{x} = F + F_{mp} - P\frac{k_1}{r}; \qquad J\ddot{\psi} = M - Pk - rF_{mp}. \tag{4}$$

How then to compare the obtained data with optical sensors (WIM-signals) and the parameters of equation (4)? We can go for further simplifications of (4) if, according to [4], go to the single-mass oscillation system that takes into account only the motion of the unsprung masses in the vertical plane. Assuming that the motion is on the way to the harmonic micro profile, we obtain [4]:

$$\frac{d^2z}{dt^2} + 2\alpha\frac{dz}{dt} + \omega_n^2 \cdot z = \omega_n^2 \cdot \varepsilon_{tire} \cdot q_0 \cdot \cos \upsilon t\ . \tag{5}$$

Here z – coordinate of vertical movement of the masses,

$\alpha = \dfrac{K_a}{2m_2}$ is coefficient of damping of the unsprung masses,

m_2 is unsprung weight of the vehicle,

$\omega_n = \sqrt{(C_{br} + C_{tire})/m_2}$ is natural frequency of the unsprung masses,

C_{br} is suspension's stiffness, and C_{tire} is stiffness of the tire,

$\varepsilon_{tire} = C_{tire} / (C_{tire} + C_{br})$ is smoothing factor of the tires ($\varepsilon_{tire} \approx 0{,}6$),

q_0 is maximum height of bumps in the road, and finally,

v is the frequency of forced harmonic tremors from the road surface.

Try to solve the problem of simulation of this equation in the form of a circuit with an unknown input to characterize the effect of mass, friction, stiffness of tires and suspension, etc. The first attempt to determine the mass of the vehicle and the frictional forces acting on the wheel is a WIM-signal approximation in the basis of certain mathematical functions. Signal approximation by polynomials of various degrees and identify their coefficients depending on the weight and friction gives not a positive result. In the harmonic approximation basis also found no linear relationship between the weight of the car and the parameters of the harmonic series, however, possible to determine the "own" the frequency of the car on the WIM-signal, which eventually led to the idea to try to solve the problem directly in the basis of differential equations.

In the first phase simulation WIM-signal with RLC-circuit of the second order (Fig. 2) with external action in the form of a trapeze with controlled quantities of the "front", "fall", the flat top and amplitude has been implemented.

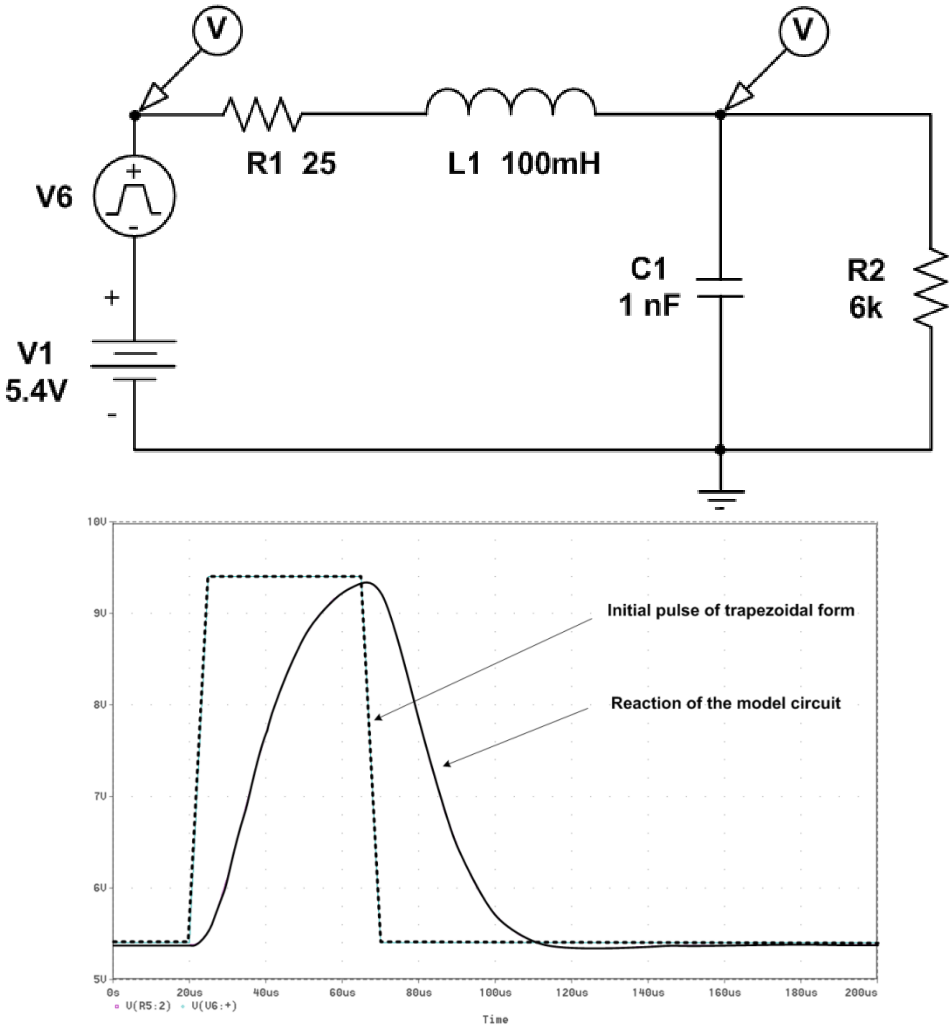

Figure 2. Simulation of WIM-signal as output reaction of the second order circuit

The figure shows part of the output response and the external action in the form of trapezoidal (see Fig. 2).

Since the output response is like to WIM-signal, we can try to find a relationship between the "mechanical" parameters of differential equations of the theory of deformable rolling wheels and its "electric" counterparts, including the weight of the car with the numerical values of the circuit elements.

However, there is much more productive idea to direct solution of linear (and perhaps non-linear) differential equations with forcing action in trapezoidal (or other shape). If the output variable of the equation to approximate the WIM-signal, optimising the parameters of the differential equation and find the relationship between the mass of the vehicle and the characteristics of the driving influence, the problem will be solved.

Among MATLAB program has been written for solving differential equations with forcing input action in the form of a trapezoid. The objective function with a weighted least square value and the maximum deviation between the WIM-signal and the output response of the differential equation has been formed. A program of "global" to minimize the objective function has been designed, since the attempts to use the existing local methods in MATLAB don't give the desired results. This approach is applied to the real signals obtained from measurements carried out by the project "Fibre Optic Sensor Applications for Automatic Measurement of the Weight of Vehicles in Motion: Research and Development (2010–2012)".

3. Data Processing

In a series of pictures below (Figures 3 and 4), as an example, are shown the right track WIM-signal *s4_70km_20_04_2012* in general and the results of optimisation for each wheel trucks with known weight for axes in the static (in coordinates: seconds, volts). The objective functions before and after optimisation *f0* and *f00*, and the vector of "optimal" parameters *x00*, including the values of breakpoints for trapezium and coefficients of the differential equation of the second order are printed, too.

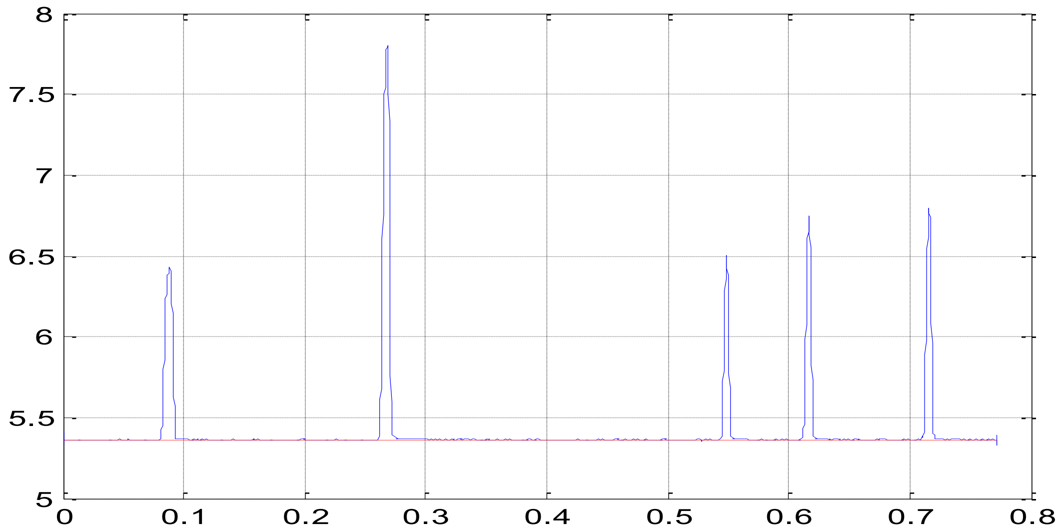

Figure 3. Typical WIM-signal from 5-axles truck (speed 70 km), right wheel, after filtering of noise

The results of calculations based on global optimisation algorithm, are as follows:

1st axis. f0 = 1.9415e+001, f00 = 3.8514e-001.
x00 = 2.1339e+000, 5.8119e+000, 1.6504e+000, 6.5675e+000, 1.2040e+000, 1.9238e+000.

2 st axis. f0 = 5.3321e+001, f00 = 1.2289e+000.
x00 = 2.8267e+000, 4.6685e+000, 1.9768e-001, 7.5414e+000, -1.1632e-001, 1.3279e+000.

3 st axis. f0 = 1.6977e+001, f00 = 3.2862e-001.
x00 = 2.3577e+000, 2.2445e+000, 1.0442e+000, 6.5046e+000, 4.5769e-002, 1.4913e+000.

4 st axis. f0 = 2.5870e+001, f00 = 4.3931e-001.
x00 = 2.5150e+000, 3.1694e+000, 1.9504e-001, 6.6501e+000, -4.3237e-002, 1.4554e+000.

5st axis. f0 = 1.7233e+001, f00 = 6.9491e-001.
x00 = 1.9662e+000, 3.3992e+000, 2.2017e-00, 16.7983e+000, 3.2466e-001, 1.5831e+000.

Initial approximation, the vector *x0 = {t1, t2, t3, u1, d1, d2}* with the values of the front, flat top and fall trapeze *t1 = 0.5, t2 = 3, t3 = 1*, representing the height of the trapezoid *u1 = Umax* and the coefficients of the differential equation *d1 = 1, d2 = 2,* (in (5) $2\alpha = d1+d2$, $\omega_n^2 = d1*d2$)), is the same for all axes. Note that the actual parameter *d1 = 0.01 * d1*.

The next task is to process the data using different speeds of vehicles with known mass and to find the correspondence between the parameters of trapezoidal signal, the coefficients of the differential equation and the mechanical parameters – mass, friction force, stiffness of tires and bracket, etc. Known mass to the right track of the axes in the static is *m = {3680, 6380, 2980, 2830, 2955}* (*kg*).

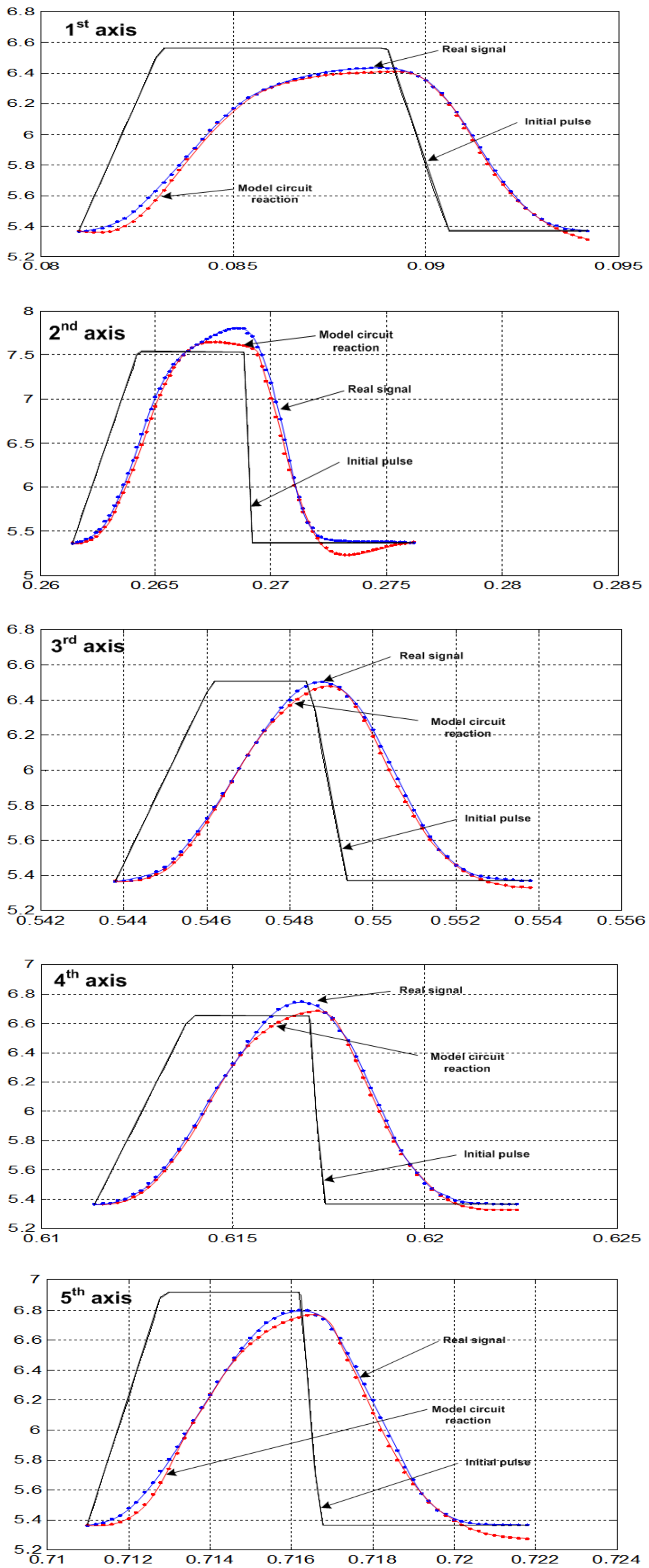

Figure 4. WIM-signal (right wheel), "optimal" output reaction and trapezoid input actions

We apply these factors (such as calibration) to determine the mass of 1-axis for the signal *s2_50km_20_04_2012 (d1 = 0.025769; d2 = 1.3015).*

Now we obtain

m1 = Ka/(d1 + d2), m1 = 5.3673e +003.
*m2 = Cbt / (1 + d1 * d2), m2 = 3.6431e +003. (S2 - m = 3682kg).*

The coefficients K_a and C_{bt} for 5th axis (*d1= 0.0032466; d2 = 1.5831; m = 2830 kg*) can be calculated as:

$K_a = (d1+d2)*m = 4.4894e+003$, $C_{bt} = (1+d1*d2)*m = 2.8445e+003$.

We apply these factors to determine the mass of the 5th axis signals *s2_50km_20_04_2012 (d1= 0.0083565; d2 = 1.8494)*
m1 = 2.4165e+003, m2 = 2.8013e+003. (S2 - m=2880 kg)

s1_70km_20_04_2012 (d1= 0.000120; d2=1.5898)
m1 = 2.8237e+003, m2 = 2.8440e+003. (S1 - m=2880 kg)

s3_90km_20_04_2012 (d1= 0.039366; d2 = 1.1662)
m1 = 3.7239e+003, m2 = 2.8196e+003. (S3 - m = 2965 kg)

It is seen that the obtained value is closer to the mass m2 and is located to an accuracy of less than 5%.

Let's verify these findings for the third axis, taking the "calibration" signal *s4_70km_20_04_2012 (d1 = 4.5769e-004; d2 = 1.4913e+000; m = 2980 kg).*

Then $K_a = (d1+d2)*m = 4445.4$ kg; $C_{bt} = (1+d1*d2)*m = 2982$ kg and the mass of the third axis for the various signals is

1. *s2_50km_20_04_2012, (d1=4.0361e-003; d2=1.7978)*
   m1 = 2.4672e+003, m2 = 2.9605e+003. (m = 3045 kg)
   relative error = -2.7750e-002,
2. *s3_50km_20_04_2012, (d1=1.8952e-003; d2=2.7360)*
   m1 = 1.6237e+003, m2 = 2.9666e+003. (m = 2900 kg)
   relative error = -2.2966e-002,
3. *s3_90km_20_04_2012, (d1 = 1.1673e-002; d2=2.5788)*
   m1 = 1.7161e+003, m2 = 2.8949e+003. (m = 2900 kg)
   relative error = -1.7586e-002,
4. *s1_70km_20_04_2012, (d1=7.9706e-003; d2=1.6711)*
   m1 = 2.6475e+003, m2 = 2.9428e+003. (m = 2945 kg)
   relative error = -7.4703e-004,
5. *s5_70km_20_04_2012, (d1=7.1044e-003; d2=1.9333)*
   m1 = 2.2910e+003, m2 = 2.9416e+003. (m = 2967,5 kg)
   relative error = -1.1545e-003.

So, as it was seen, in all of calculations, the relative error wasn't exceeding 3% of the measured weight's value.

4. Conclusions

It seems that everything is fine. But ... . The priory knowledge of the values and suspension stiffness of the tire, or one of them, is need for successful application of the method. Unfortunately, the problem of determination of coefficient of rigidity from the results of the optimisation hasn't been resolved, so we need to use its values from references [4] or other sources now.

For example, it is a graph (see Fig. 5) for the ZIL-130 truck vehicle's tires, noting that the damping capacity of the tire due to intermolecular friction rubber and internal friction between the elements of the tire [4]. The presence of friction leads to the hysteresis loop on the elastic characteristics of the tire, which becomes narrower with increasing velocity.

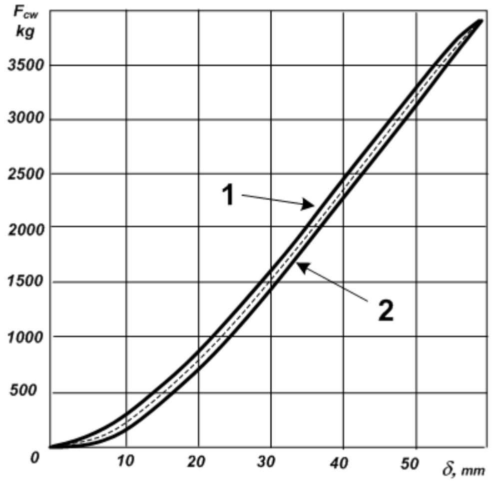

Figure 5. Elastic characteristics of the tire air pressure is 3 kg/cm^2 (here F_{cw} is an elastic force in tires), and 1 – loading, 2 – unloading curves [4].

The knowledge of static stiffness values for the currently operating commercial vehicles would be helpful for implementation of the results of this approach or its modified version into weight-in-motion (WIM) technologies because of high accuracy (till 3%) of it.

Relatively long time of signal processing of fibre-optic WIM sensors because of a weighted least square algorithm of global optimisation usage may be mentioned as the disadvantage of this approach. But the problem is – it can be solved by the signal from each axle of the vehicle parallel processing.

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SIGNAL PROCESSING OF THE FIBER OPTIC SENSORS IN THE COMPLEX USE OF THE STATIC AND DYNAMIC VEHICLE WEIGHING SYSTEM

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One of the dynamic weighing challenges is to recognize the overloaded vehicle in the traffic flow. In this article, it was shown the possibility of the signal processing in the dynamic weighing devices using the fibre optic sensors, in order to make the decision of the overloaded vehicle presence on the road. There also were proposed the processing algorithm of the data received from the output of the fibre optic sensor; as well as the requirements for the elements and the blocks of the algorithm were defined. There was also introduced the concept meaning of the reference system. As the reference system there was proposed the possibility to use the digital filter with the finite impulse response. The estimation method of the filters' weight coefficients was proposed.

Also, several tests of the algorithm were made for the vehicle identification with the reference load.

Keywords: dynamic weighing, digital data processing, system identification

1. Introduction

Nowadays state of the transport networks in the European countries and its continued development involves the extensive usage of the intelligent transport systems (ITS). With the help of ITS, it is possible to solve the problems that can ensure smooth and uninterrupted traffic and the problems, which are associated with the need of maintaining the quality of the road surface.

In particular, many highways and especially high-speed lines have the limited access of the trucks' axle weights on the road pavement [1]. To control this access the following ITS components are used: the static and dynamic systems of the weighing vehicles.

The procedure of the static vehicle weighing requires, firstly, stopping the movement of the vehicle in the desired direction and then to drive the vehicle to the special area for it's weighing. Obviously, all of these operations go in contradiction with the task of ensuring the smooth and uninterrupted traffic.

The dynamic vehicle weighing systems or weight-in-motion systems (WIM) allow weighting the vehicles in motion that greatly expands the range of its applications. However, for the present, it is economically not effective to use the dynamic weighing systems, mostly due to the features required by the electronic sensors [2].

The existed weighing systems of the vehicles use the various types of the electronic sensors [3], but the main ones are as follows:

- Capacitive sensors (Capacitive pad, capacitive strip).
- Piezoelectric sensors (Piezo-electric cable).
- Tensometric sensors (Bending plate, Load cell).

But the existing sensors that are used for the weighing of the moving vehicles have either the high cost of the installation and the maintenance, and usually the short term of service, or have the low accuracy of the determining the mass of the vehicle [2] .

It is possible to reduce the costs of the installation and the maintenance of the dynamic weighting systems by combining it with the static vehicle weighing system. In this case, the dynamic vehicle weighing system should solve the task of the pre-selection of the overloaded vehicles from the traffic flow that will be weighted, subsequently, with the help of the static system.

The task of the ensuring the uninterrupted traffic flow is resolved the better, the more accurate will be the selection of the overloaded vehicles from the traffic flow, i.e., the less errors are in the decision of the dynamic vehicle weighing system.

Recently, it is regarded the possibility of the fibre optic sensor use, as the alternative in sensors of the dynamic vehicle weighing system [1]. The main advantages of the fibre optic sensors are the long lifetime (about 12 years) and the low cost of the system in general, as well in both: the installation and the maintenance during the following years [5, 6].

Regardless of the type of the sensor, there is one and the same parameter that characterizes the weight of the vehicle. When the vehicle passes the special working part of the sensor, and, due to the weight of the vehicle, the working part of the sensor is deformed and, by means of this, changes of the electrical signals occurred. Then the sensor registers those changes of the electrical signals and gets the information about the weight of the vehicle [3, 4].

However, in the present, there are not enough researches and investigations having been made, concerning the signal processing from the fibre optic sensors' output, to make the full implementation of such kind of sensors in the dynamic weighing systems. Also, the operation of such a kind of dynamic weighing systems was not analysed, especially applying it to the problem of the identification of the overloaded vehicles.

2. The Features of the Electronic Sensors Application in the Dynamic Weighing Systems

The dynamic weighing systems are positioned as the devices that detect the appropriate static mass of the axle or of the whole vehicle, on the basis of the measurements of the axles' dynamic mass or on the basis of the whole vehicle-in-motion (WIM).

In general, the dynamic weighing systems are divided into two big groups, depending on the vehicles' speed limits during the weighing:

- Low speed (less or equal to 15 km/h).
- High speed (more than 15 km/h).

The division of the dynamic weighing systems by the vehicles' speed was made due to functional and accuracy limitations [5].

There are a lot of different factors that affect the performance of the dynamic weighing systems, both, at low and at high speed. Some of these factors are inherent in the certain selected dynamic weighing system; in particular, in systems that uses the force sensors. Of course, others and equally important factors, that affect the ability of the dynamic weighing system, are common to the WIM-technology in general.

The main factors associated with the sensor readings of WIM are:

- Characteristics of the WIM sensor location.
- Vehicle specifications that leads to errors in the readings of the sensors.
- Environmental attributes that affect the WIM sensors.

The first two types of the factors mainly affect the changes of the centre of mass of the vehicle during the weighing. But the temperature changes affect the entire result of the weighing process in general.

The lateral inclination of the vehicle shifts the centre of mass and thus it leads to the shift of the load in the direction of the "lower" wheel. The slope in the direction of motion leads to a transfer of load to the "lower" the axle (-s). Therefore, the weighing on the hillside shows different results, compared with the weighing on the straight surface.

The maximum possible error for the WIM called fluctuations of the car. With respect to the fluctuations of the car, there are two fundamental fluctuating motions. These are: the car frame oscillation with a natural frequency from 1 to 3 Hz, depending on the load, and the axis oscillation with a frequency of about 10 Hz [7, 8].

No less significant errors occur when the ambient temperature at the location of the sensor ADD.

The errors that occur due to the ambient temperature changes at the location of the WIM sensor are not less significant.

On Figure 1, for example, the loading-unloading diagram is shown, that has been obtained with the different ambient temperatures at the location of the fibre optic sensor.

The optical response of the sensor decreases with temperature due to the material of the sensor's shell that becomes less pliable. The increase of the area of the hysteresis loop at low temperature, possibly, is explained by the heating of the sensor during the test (approx. 20 min.).

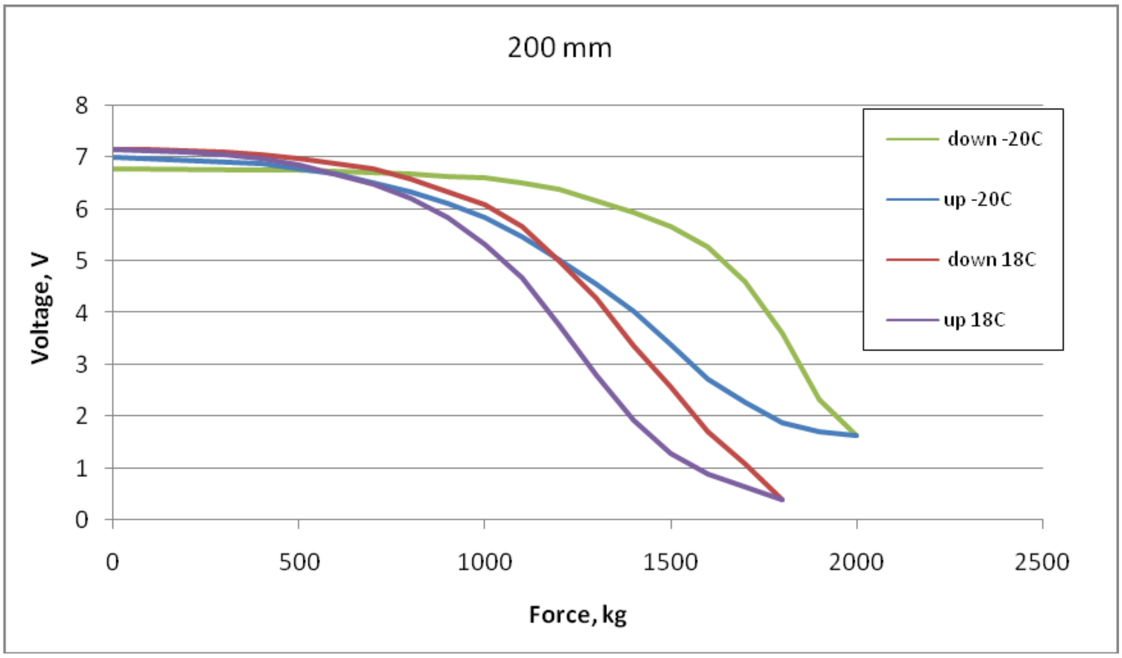

Figure 1. The relationship of the voltage output of WIM sensor from the different temperature meanings

The heterogeneity of the factors listed above, as well as their random nature, makes it almost impossible to use the direct methods of converting the electrical signal from the output of the sensor to the axles' weight or to the whole weight of the vehicle. The accuracy of such conversion is in the range from 40 to 120% of the actual weight of the vehicle [1].

3. The Formalization of the Decision-Making Task about the Overloaded Vehicle

As stated above, one of the tasks of the dynamic weighing is the task of the detection of the overloaded vehicles in the traffic flow. In this case, the weighing task will be transformed into the decision-making task – if the vehicle is overloaded or not.

The decision-making tasks are usually solved by comparing the current event with some the so-called reference one.

In the systems with electronic sensors, the standard or reference can be specified either in the form of the reference signal, or as a device, which carries the characteristics of the reference signal.

In the dynamic weighing systems where fibre optic sensors are used, the reference signal from the sensors' output should have the characteristics that correspond to the true weight of the vehicle detected by the sensor. As there are random and regular destabilizing factors that distort the signal from the fibre optic sensors' output, the reference signal can only be formed as the result of the averaging signals from the output of the same sensor due to repeated overriding of the vehicle loaded with the reference weight.

Thus, the reference signal – this is the response of the sensor in some measuring system, that corresponds to the averaged response of the sensor of the real system to the repeated overriding of the vehicle loaded with the reference weight. The corresponding conditional system will be called – the reference system.

After the reference system is created, the decision-making tasks concerning the vehicles' accordance to the allowable weight for a given road can be made, for example, by the correlation analysis technique [10].

This calls to set the model of the reference system and to set its parameters in such a way, that the output signal would have characteristics that corresponds to the maximum of the allowable weight of the vehicle for the particular type of the road.

Comparing the responses from the sensors' output of the real system, when the sensor detects the passing vehicle only once, with the response at the reference systems' output, using the correlation method, it is possible to determine what event rate is bigger – has the vehicle the greater weight than existed in the reference system or the smaller one.

4. The Reference Dynamic Weighing System and its Features

As stated above, the decision-making task concerning the vehicles' overloading can be solved by comparing the sensors' response of the real systems' output with the sensors' response of the reference system. Besides, the sensors' response of the reference system should be in accordance with the average response of the real systems' sensor to the repeated overriding of the vehicle loaded with the reference weight.

The creation of the adequate reference system is a complex technical challenge that requires taking into account all the destabilizing factors that mentioned above, which affect the WIM sensors. And, as among the destabilizing factors there are vehicle specifications that lead to the errors in the sensors' readings, the design of the reference system can only be applied to the specific and pre-selected vehicle.

In this paper, there is an example of the design of the reference truck weight identification system for the truck brand "Volvo FH12" (Figure 2).

Figure 2. "Volvo FH12" truck

On Figures 3 and 4 there are shown the signals obtained from the fibre optic sensors' output, which is installed into the road, when the sensor is passed by the empty vehicle and by the same loaded vehicle with the reference weight; vehicle type "MAN FH12".

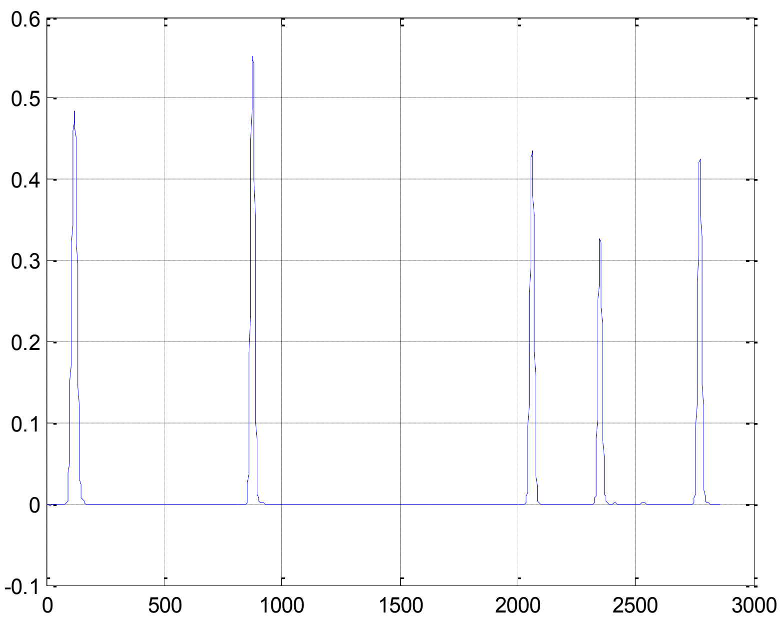

Figure 3. The response of sensors' output, when the empty truck passes it at the speed of 90 km/h

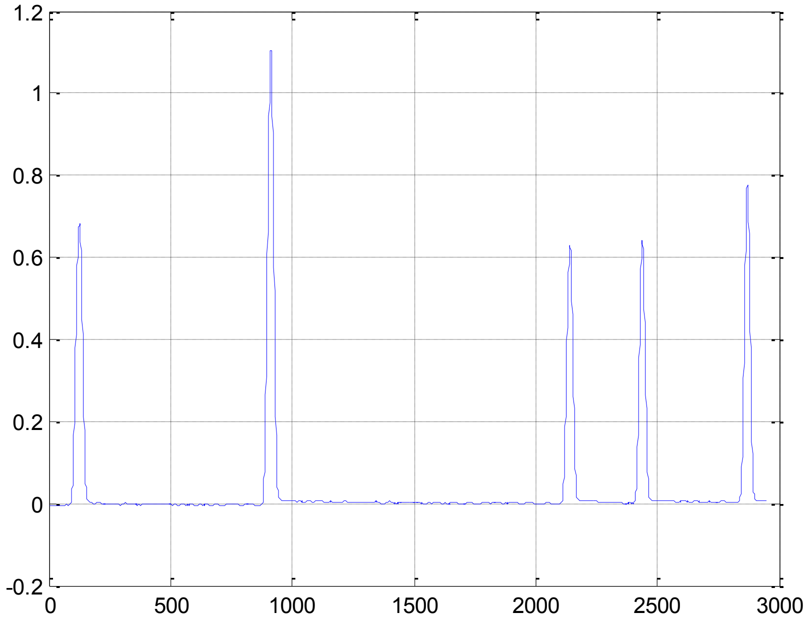

Figure 4. The response of sensors' output, when the truck, loaded with the reference weight, passes it at the speed of 90 km/h

From the figures, showed above, it is possible to see, that when the truck passes through the sensor placed into the road, each of the five axles of the "MAN FH1" vehicle appears at the sensors' output as leap of the voltage (vertical axis). The set of five leaps of the voltage on the time axis (the horizontal axis shows the numbers of discrete signal samples in time) – is the system response from the passage of the selected vehicle type.

It is also can be seen that the responses of the sensor while passing the empty vehicle and the loaded vehicle, with the reference weight, are different. However, the degree of the responses similarity or difference can be determined statistically only. The procedure of the comparison of responses is complicated by the fact that the speed of the vehicle when driving over a sensor is not known in advance and, therefore, the location of the voltage leaps on the time axis is unknown.

These circumstances brings us to the need of the data pre-processing in the fibre optic sensor, for the purpose of bringing the sensors' output responses into the one and the same time frame.

As well, in the same time frame should be generated the reference systems' response from the vehicle of the given type, that is loaded with the reference weight and that passes the sensor. The device that generates this reference response – is the reference system.

To bring the response from the sensors' output into the same time frame, it is needed to make the following calculations:

- The calculation of the centre of mass of statically weighed vehicles of a given type.
- The calculation of the centre of mass of dynamically weighed vehicles of a given type.
- The calculation of the speed of the vehicle of a given type Basing on the assessment of the decentration of the mass of the dynamically weighed vehicle with respect to the centre of mass of the statically weighed vehicle, and, knowing the speed of the latter, the peak voltage amplitude response is recalculated from the sensors' output in the new coordinate system, which corresponds to the single time frame.

To reduce the errors associated with the temperature sensor instability, during the recalculation of the peak voltage amplitude response from the sensors' output, there are calculated and introduced the correction coefficients.

The transformation procedure to the same time frame of the WIM sensors' response is sufficiently completely described in [11].

4.1. The Reference Signal Normalization and the Conception of the Reference System

As the reference signal – it should be the response from the WIM sensors' output that is normalized to the common time frame, and contains the information about the vehicles' weight that passes the sensor.

The reference signal is generated by the averaging the values of the voltage peaks' amplitudes response from the sensors' output resulting from the repeated calibrating overriding of the specified vehicle type with the reference load.

In this case, for the averaging procedure it is very important to know, how many sensors are installed for being passed by the vehicle, or how many times the vehicle passes the sensors, all of this will result the averaging.

Thus, there is an opportunity to get two signals in one time frame.

The first signal corresponds to the distribution of the voltage peaks' amplitudes of the statically weighted vehicle, and the second one – to the distribution of the voltage peaks' amplitudes in the reference signal.

The work of the WIM, in this case, can be interpreted as the work of some equivalent electronic system. At the input of this system was sent the reference signal and the response of this system was the signal that corresponded to the distribution of the voltage peaks' amplitudes of the statically weighted vehicle of the specified type and with the reference load.

Consequently, this system will be called – the reference system.

4.2. Description of the Algorithm That Determines the Characteristics of the Reference System

The main element of the reference system is the filter with the finite impulse response, which transforms the reference signal into the corresponding distribution of the peaks' amplitudes of the statically weighted vehicle of the specified type and with the reference load. The quality (accuracy) of the transformation depends on the correctness of the definition of the filters' weight coefficients.

Due to the complexity of the exact analytical description of the initial signals it was offered to receive the adequate value of the filters' weight coefficients by the method of systems' identification [10].

On Figure 5 the structure of the algorithm is shown for defining the characteristics of the reference system.

The main element of the structure is the filter with variable weight coefficients (the transversal filter).

On the filters' input the reference signal is sent.

The task of the algorithm is the following: to minimize the error of the reference signal reproduction by adjusting the parameters of the transversal filter. As the reference signal, the signal has been taken, that corresponds to the distribution of the voltage peaks' amplitudes of the statically weighed vehicle of the specified type and with the reference load.

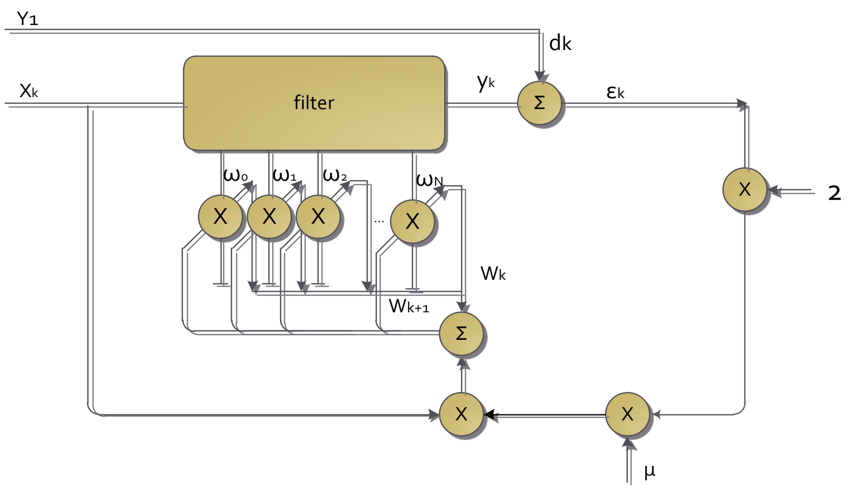

Figure 5. The structure of the adaptive algorithm for determining the weight coefficients of the transversal filter

To obtain the weight coefficients of the transversal filter the least squares method [10] has been used. This adaptive algorithm has been taken due to the fact that it works in real time, i.e., there is no need to accumulate errors from the sensors. The use of other adaptive algorithms, such as Normalized LMS, Variable step size LMS and sign algorithm LMS, do not lead to the significant improvements in the calculation of weight coefficients.

The calculation of the coefficients is carried out according to the following formula:

$$w\ (k+1) = w\ (k) + \ \mu e\ (k)\ u\ (k) * 2, \qquad (1)$$

where: μ – positive coefficient, which is called the size of the step;

$e(k)$ – the replication error of the reference signal;

$u(k)$ – the content vector of the delay-line on the k-step.

Later, these weight coefficients are stored in the form of the constant filters' weight coefficients of the reference system.

5. The Algorithm for the Overloaded Vehicles' Identification

During the test of the proposed algorithm two reference systems have been formed (for the reference signal of the vehicle that is fully loaded; the vehicle brand is "MAN FH12", and for the reference signal of the empty vehicle of the same brand "MAN FH12").

The converted signal from the fibre optic sensors' output was sent to the discrete filters of the corresponding reference systems, and there were estimated the relative standard mean square errors on the filters' outputs.

In the Table 1 there are shown the following results that have been received during the working process of the algorithm of the systems identification.

Table 1. The table of the output results of the algorithm for the vehicles' identification

Vehicle passing options with different weights		Discrete filter Nr.1 (reference of empty vehicle)		Discrete filter Nr.2 (reference of loaded vehicle)	
		Speed, 70km/h	Speed, 90 km/h	Speed, 70 km/h	Speed, 90km/h
Number of empty vehicle passing	1	0.0983	0.1044	0.5499	0.4444
	2	0.1273	0.0740	0.5923	0.4093
	3	0.1051	0.0725	0.5605	0.4084
	4	0.0602	0.0719	0.5023	0.4081
Number of loaded vehicle passing	1	0.4294	0.2410	0.2018	0.2186
	2	0.3864	0.3436	0.1483	0.0568
	3	0.3250	0.3263	0.2204	0.0878
	4	0.5113	0.3436	0.1167	0.0568

As it can be seen, not all the results are well-defined. This could happen due to the fact that the fibre optic sensor has not been tested for the spatial homogeneity of the sensor response over the period of the working zone. In the data used, the possible errors can occur. This is associated with the fact that the signals are not recorded in one day, but for a certain period of time, when the connection and the disconnection of the equipment from the sensors takes place.

According to the results, it is possible to conclude that the designed system copes with the task of the vehicles' identification by the excess of the permitted maximum load on the road.

6. Conclusions

In this paper, there has been shown the possibility of the joint use of the dynamic and the static weighing systems. Under such condition, the dynamic weighing systems should solve the task of the preliminary selection of the overloaded vehicles in the traffic flow.

As it is shown in the results of the work, this direction for the future research is relevant and promising. For now there is no dynamic weighing system that is in service, where the fibre optic sensors are used. The obtained results allow using the system for the determination of the overloaded vehicles in traffic flows.

The use of the different, by the structure, reference systems may increase the probability of the correct decision-making.

One of the main and the daunting problem is to create a set of the reference systems for different modes of transport. The creation of such a set for the large number of vehicles is rather expensive venture. In this connection, the development of the automated systems, which collect the statistical data and form the reference identification systems of the overloaded vehicles, is really actual task.

Acknowledgements

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TRANSIENT RESPONSE OF A SMALL-BURIED SEISMIC SENSOR

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A model of small-buried seismic sensor transient response excited by a car tyre interaction with asphalt-concrete road pavement is proposed. It is supposed that a seismic wave received by the sensor is the vertical component of surface Raleigh wave. The model is based on supposition that a tyre footprint is acceptable to consider as some array of point sources of these waves. The proper algorithms permit to vary different parameters of the array excitation, as to footprint dimensions, load distribution, motor car velocities and others. The set of Matlab codes for seismic transient pulses modelling and processing has been worked out.

Keywords: weigh-in-motion system, tyre footprint, impact, road pavement reaction, sensor response modelling

1. Introduction

Economic situations in majority countries are visibly affected by range of automotive load transportation, and, therefore, by satisfactory condition of road networks. Degree of road deterioration is determined mainly by traffic activity and excessive gross weight of laden trucks. In accordance with present standards, certain loading for a single axle of a motor car has to be restricted to some maximum allowable value. Exceeding of it proper sanctions are assumed. Very promising way to estimate the loading on certain axle is application of weigh-in-motion (WIM) systems [1–6]. There are many versions of WIM. Some from them have used subsurfaced small-buried seismic sensors within road pavement [3, 4].

Output response of that sort of sensor is a time series of some non-stationary transient signals. The number of pulses is equal to the number of axles of the motor car, which is passed over the sensor at that time interval. At first sight all the pulses appear to be similar one another. However, some theoretical considerations, as well analysis of experimental data, demonstrate certain differences existing among them. For successful designing a WIM system the nature of these delicate differences ought to be discovered and interpreted.

The goal of a WIM system modelling is to work out a method to filter individual differences in features of those pulses. In this paper the algorithm is developed based on modelling of a small-buried seismic sensor response excited by forced impact distributed along a car tyre footprint to asphalt-concrete road pavement. It is supposed that a seismic wave perceived by the sensor is the vertical component of surface Raleigh wave [7, 8] propagating in the road pavement top layer.

It is assumed the tyre footprint should to be considered as some discrete array of point sources of surface Raleigh waves each with own exciting loading distributed along the footprint. A transient signal created by interferences of these waves is received by the seismic sensor. If a sensor depth position (that is a distance of it from pavement air surface) and tyre footprint dimensions are assigned as some initial conditions the proposed model permits to:

a) vary the function, which describes tyre contact pressure distribution inside the footprint contour,
b) specify an automobile velocity,
c) match a rolling road resistance coefficient,
d) take into account of wind velocity component oriented along the road, etc.

Results of modelling are sensor response forms, which ought to comply with conditions specified above. These forms may be used as a starting material for formulation of the target inverse problem namely estimation of loads on individual axles of a motor vehicle passed over the WIM sensor.

The organization of the paper is as follows. Some qualitative considerations concerning wheel-road interaction are stated in Section 2. The problem in Section 3 relates to calculating of a seismic pulse basic form excited by a unit point mass body moving with some friction along a horizontal road. In Section 4 the model of a pulse excited by tyre-road contact footprint is suggested. The tyre footprint is considered to be some discrete dynamic array of surface Raleigh waves sources with exciting loadings distributed all along the footprint. In Section 5 some potentials of that model are demonstrated with examples. Features of Matlab programs worked out to illustrate resources of the models considered in this paper are briefly discussed.

2. Some Features of Wheel – Road Interaction

An axle loading W is translated to a footprint as a nonuniformly distributed wheel pressure. It is described by a certain function F_p(x, y), which is depended on tyre elasticity forces depicted by even temporal modes, as well as friction forces caused by elements of a pneumatic tyre tread. As the wheel is in rolling motion along the axis x with some linear velocity V and angular velocity ω_w, the radial deformation of the tyre tread is changed abruptly in time with a really complicated manner. It is amplified in the thread front part, but it is reduced in the back part of it. These reasons are reflected in the friction forces as the dominant odd modes.

As a result, at the *a-c* part of footprint the friction forces have the same directions (Figure 1) as the tyre elasticity forces, but along the *c-b* part their directions are opposed. Therefore, wheel pressure F_p and road reaction R_z diagrams are nonsymmetrical relative to the vertical axe z passed through the wheel centre.

The extrema of pressure and reaction forces are displaced from the axe z by the shift s. Thus, a value of s should serve as a measure of wheel – road interaction. Unfortunately, exclusive multifactorial complexity of considered process not yet permits to create the mathematically strict description of it. A qualitative picture of wheel/road interaction (Figure 1) is set out in [9]. This interaction takes place within the bounds of some contact pavement surface referred to as a tyre footprint.

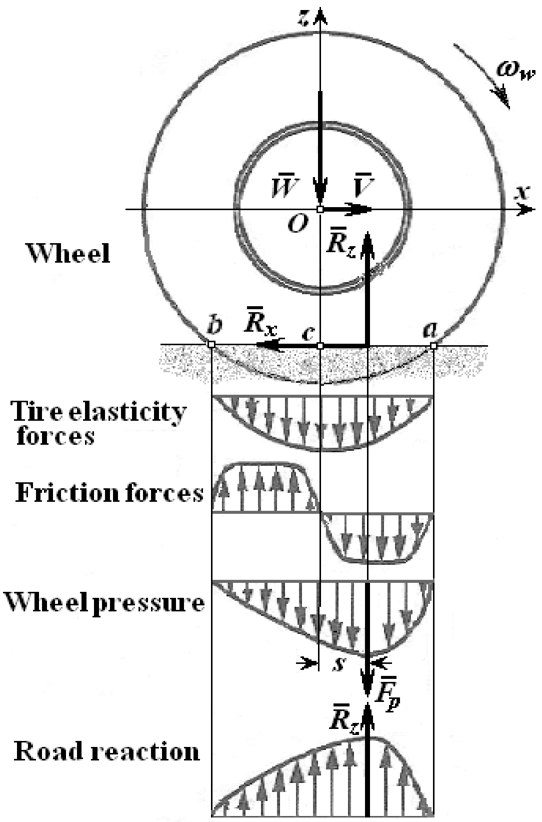

Figure 1. Wheel – road interaction picture (adapted from [9])

3. Response on a Unit Point Mass Movement

The problem described in this part is derivation of a seismic pulse form excited by a unit point mass body moving with certain friction along a smooth horizontal road. Figure 2 shows the sketch of the task. An omnidirectional (isotropic) seismic sensor is placed on some depth h from road surface and it is superposed with the origin O of Cartesian coordinates system. A point body moves from initial position $t = 0$, $x = x_0$ to right along the plain pavement surface with constant velocity V. It is supposed that x_0 is a negative value. The body experiences an influence both force of weight W and friction force F too.

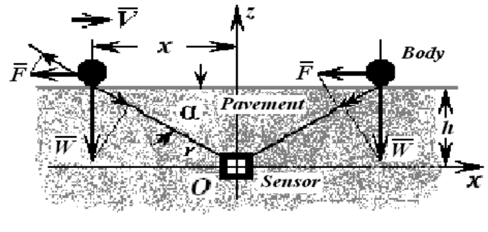

Figure 2. Excitation of seismic sensor by a unit point mass body movement

Instantaneous position of the body concerning the sensor describes by distances x, r and an angle α where

$$x = x_0 + Vt, \quad r = (x^2 + h^2)^{1/2}, \quad \sin\alpha = h/r, \quad \cos\alpha = x/r. \tag{1}$$

Movement of this body excites seismic oscillations in pavement layer propagating along the road surface as the Raleigh type waves with velocity V_R. The current pressure P perceived by the sensor depends on the instantaneous sum of projections onto running radius – vector r of the forces W and F.

It is seen from Figure 1 that projections of W will alter their directions as soon as the sign of x is changed, hence, one can describe

$$P = (W \cdot \sin\alpha - F \cdot \cos\alpha) / \sqrt{r}\,, \qquad (2)$$

where the reverse squared root dependence of Raleigh surface wave intensity from distance [4, 5] has to be taken into account. If a sensor has to response on normal, or z, component of force P only, then it is necessary to project the force in Eq. (2) to z-axis. Allowed for (1), the result can be written as

$$P_z = W\,(1 + k_F x / h) h^2 / r^{5/2}\,, \qquad (3)$$

where the value of $k_F = F/P$ may be considered as a rolling friction coefficient.

As the Raleigh surface wave propagates along the r from the point of instantaneous position of the moving body to the sensor it should be delayed in time on $t_R = r/V_R$. Temporal scale of sensor has to take it into account. Therefore, "sensor time" t_s has to look as

$$t_s = (x - x_0)/V + (r - r_0)/V_R\,, \qquad (4)$$

where $r_0 = (x_0^2 + h^2)^{1/2}$. Equations (3) and (4) may serve as a basis for modelling of sensor responses time forms initiated by a moving body. Certain results are presented on Figure 3 with some variations of k_F.

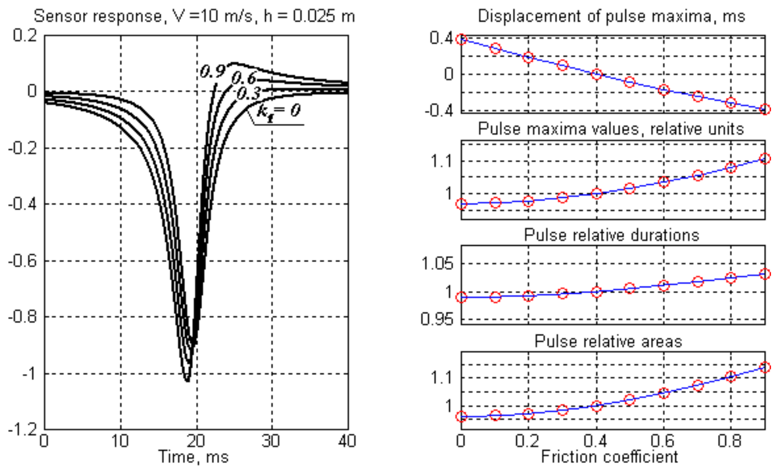

Figure 3. Pressures pulses forms versus rolling friction coefficients

It should be noted that in accordance with Eqs. (1) and (4) the distance x and sensor time t_s are in nonlinear relation due to second item in (4). It is especially significant in a region of small times.

The plots on Figure 3 represent the results of seismic wave propagation in asphalt-concrete road pavement. The exact value of Raleigh wave velocity is unknown but it perhaps is about $V_R = 400$ m/s [10]. It is seen from the left plot of Figure 3 that the growth of friction coefficient leads to certain asymmetry of sensor transient response with respect to maximum value of it. It is accompanied by increasing of pulse amplitudes, durations and areas. In the same time the maximum of the pulse is shifted with some lag in opposition to direction of motion. These features are shown on graphs placed in right panel of Figure 3.

4. Seismic Pulse Excited by Tyre-Road Contact Footprint

The model described in the previous part permits to derive a seismic pulse form excited by a unit point mass. Essentially, solution of this task should be considered as a certain Green's function. Hence, it may be used to find a form of response caused by motion of some finite-dimensional body with known distribution of mass along it. Such the solution is reduced to modelling of interaction of seismic pulses excited by different parts of the moving body taking into account the lags.

That approach may be conformable with the problem of seismic sensor response excited by forced impact of a car tyre footprint to road pavement. Unfortunately, any analytical definitions, neither of mass distribution along a footprint, nor normal component of road reaction on pressure acting, are not discovered in accessible reference sources. In this paper, the normalized function

$$W(x) = \begin{cases} \sin(\pi x / 2x_{\max}), & x \in [0,\ x_{\max}] \\ \\ \cos[\pi(x - x_{\max}) / 2(l - x_{\max})], & x \in [x_{\max},\ l] \end{cases} \tag{5}$$

is proposed to describe the distribution above as a piecewise smooth approximation where l is the footprint length, x is the current coordinate along footprint. The value of $x_{\max}$ is the position of maximum pressure (or road reaction, see Figure 1) point. It is depended both on a car velocity and a rolling friction coefficient. That maximum is displaced from the point of footprint centre in the direction of motion of the car. The value of this shift would be associated with friction coefficient and depends on road rolling resistance, car velocity, aerodynamical factors, wind vector, etc.

However, the numerical modelling practice have been demonstrated that more promised results have to take place with upgraded formulation of (5), namely

$$W_{\mathrm{M}}(x) = W^{\alpha}(x), \qquad \alpha < 1. \tag{6}$$

It have been established with numerical experiments that more pertinent values of α should be situated about 0.3 – 0.5. Behaviour of distribution (6) under different α with the regard for Eq. (5) is illustrated on Figure 4,

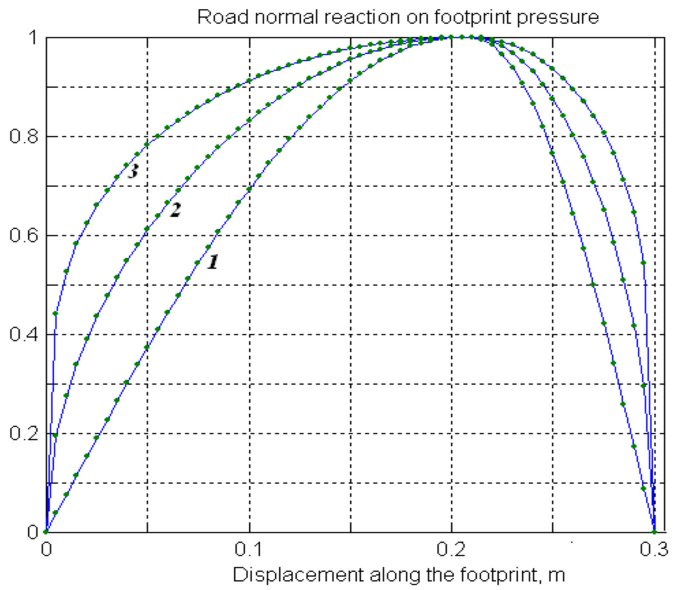

Figure 4. Supposed normal road reaction distributions: 1) $\alpha = 1$; 2) $\alpha = 0.5$; 3) $\alpha = 0.25$

where the length of car tyre footprint in (5) is taken as $l = 0.3$ m with $x_{\max} = 0.21$ m. It is conformed approximately to friction coefficient value nearly 0.3.

The curves on Figure 4 are not contrary to proper graphs, which have been given in some reference sources (see Fig. 1) to explain nature of road reaction on a footprint contact at least in qualitative sense.

In order to calculate seismic sensor transient response initiated by a body with finite sizes it is advisable to replace the body by equivalent source of seismic wave in the form of some one – or two – dimensional discrete array. The array is oriented in the direction of supposed motion of the body. It consists of well-defined number of point sources of surface Raleigh waves each with own exciting loading. These loadings are distributed along the body, for example, some footprint, in accordance with Eqs. (6) and (5). Every element of the array excites own Raleigh wave and makes contribution into summarized normal pressure component influenced on a sensor.

Described approach permits to find a sensor response on short-term impact under simultaneous contact of tyre footprint with a road pavement. Symmetric load distribution along the footprint is shown on Figure 5. The middle panel presents relative contribution into total pressure from different elements (i.e. footprint parts located along a road pavement surface) of a one-dimensional equivalent array.

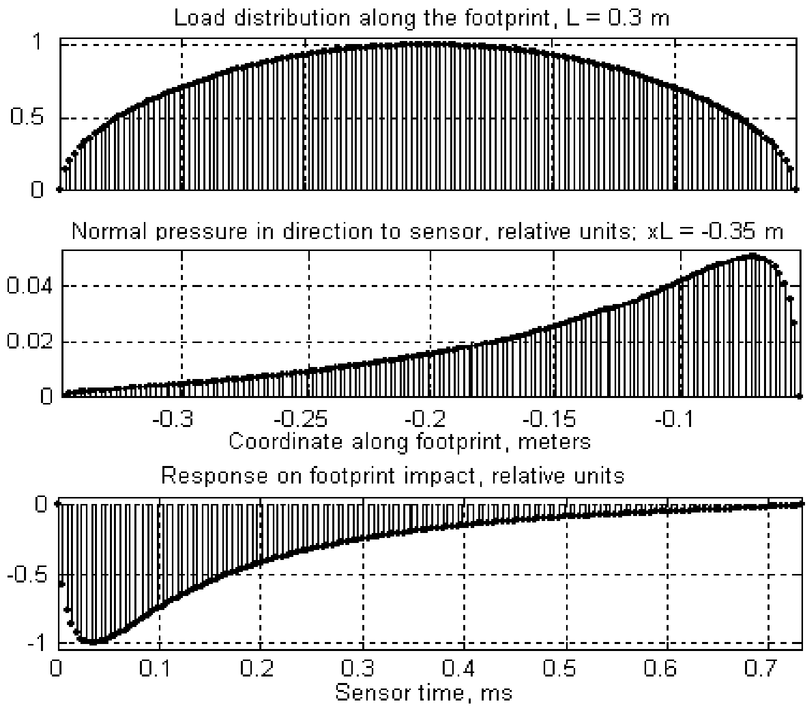

Figure 5. Pulse response initiated by tyre footprint contact with a road

It is supposed the sensor is situated on the depth h = 0.025 m from the surface. Let the footprint width is a constant. Coordinates along footprint are counted from sensor position (as the value of x on Figure 1). Finding of sensor reaction in those conditions is, in essence, a one-dimensional problem consisting in evaluating of the pulse response of the sensor with delta stimulus. Such the response after normalization is plotted on Figure 5, the lower panel.

It would be noted that natural experiment by means of the direct instrumental measurement of pulse response is rather difficult in realization. It is possible that computer modelling is the only one way to decide this problem by relatively inexpensive tools.

5. Variations of Seismic Pulse Forms

As a function of weight, a seismic pulse form in WIM applications has to depend on many arguments and can be described by different features. Being realized as Matlab codes the models considered above allow analysing relative influence of some factors on inherent structure of the pulse and picking out the most correlated with WIM aims.

In computational sense, finding of a pulse form excited by a moving array with N elements reduces to calculation of some matrix. Every string in it is an elementary pulse. It is conformed to appropriately delayed motion of an individual element of the array (see Eqs. (1–4)).

That matrix is:

$$P = \begin{bmatrix} P_{11} & P_{12} & \dots & P_{1K} & 0 & 0 & \dots & 0 \\ 0 & P_{21} & P_{22} & \dots & P_{2K} & 0 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & \dots & 0 & P_{N1} & \dots & \dots & P_{N,K-1} & P_{NK} \end{bmatrix}, \tag{7}$$

where K is the prescribed number of array element positions, or shifts, along x-axis on Figure 1. Every string in (7) is completed by zeroes in start and finish points in order to equalize the lengths. Current position of the element P_{NK} determines the total length of any string. As sensor time t_s depends on x, nonlinearly plain addition by columns in (7) is not correct to have the right response form. Certain interpolation for every string has to be done preliminarily using the Raleigh wave minimal arrival time h/V_R as the step.

It can be observed that computation of the matrix (7) is equivalent to convolution of the unit point pulse (3) with the footprint loading distribution (6). The latter should be considered as a function of time, which is revealed oneself in process of footprint rolling over the sensor.

As a sounding example, this method may be applied to the problem of correlation of pulse form with footprint length solved by computational experiments. In order to correspond with (7) it has been supposed the seismic signal is formed by linear combination of some delayed pulses. Each from them is excited by proper element of discrete array, which is considered as a certain equivalent of the footprint. The vehicle velocity V, as well as the position, or shift s from a loading centre, of the road reaction R_z maximum value (see Fig. 1), are treated as the constants. Results are shown on Figure 6.

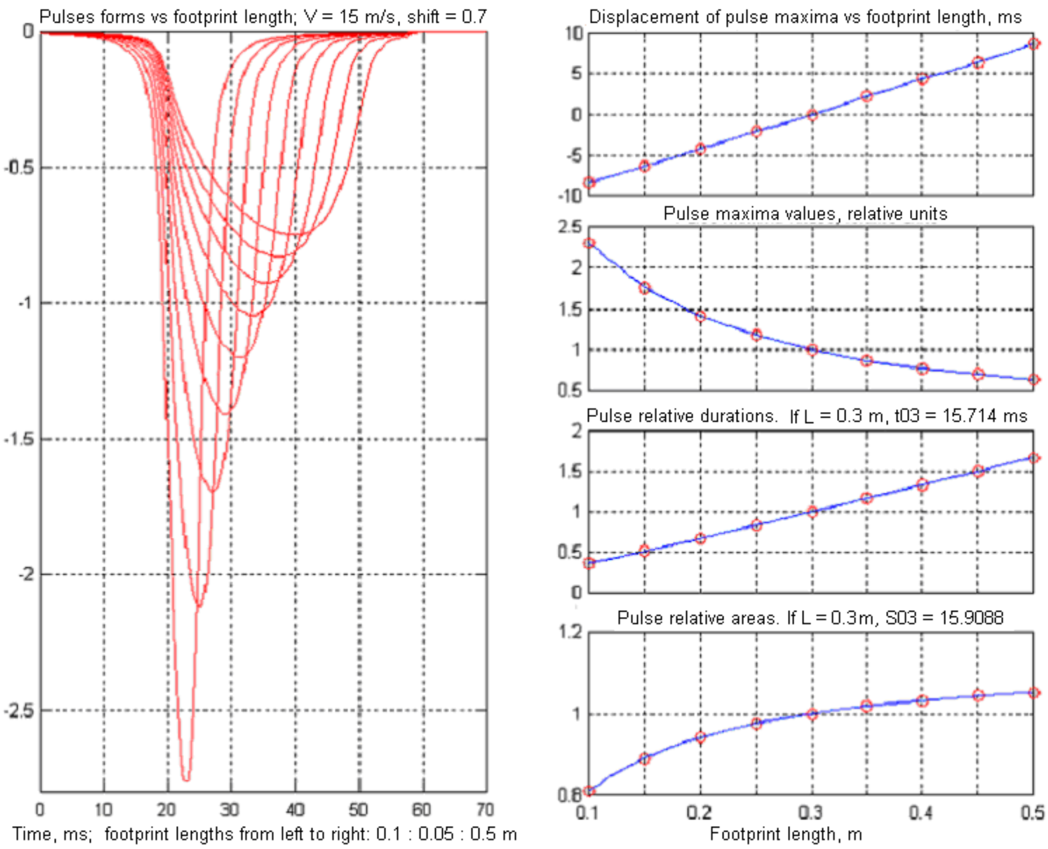

Figure 6. Forms of pulses vs footprint lengths

In particular, it is seen from the right panel of Figure 6 that duration of the pulses depends on footprint length rather linearly, in contrast to other characteristics of these transients. That fact may be used in designing of WIM systems.

6. Conclusions

In this paper, the model of seismic sensor excitation by automotive tyre footprint pressure is suggested. It is based on replacement of a footprint by certain discrete array considered as an equivalent source of a transient seismic signal. Proclaimed structure of the model is not contrary to widespread ideas of a motorcar wheel interaction with a road pavement. The model is displayed the temporal form of that pulse, which is described by a convolutional matrix reflected the interference of Raleigh waves from different parts of the array. The appropriate computing procedures have been realized in Matlab. Resulted pulse forms may be used as a starting material for formulation of the target inverse problem in designing of WIM systems namely estimation of loads on axles of a car.

Acknowledgements

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CUMULATIVE INDEX

COMPUTER MODELLING and NEW TECHNOLOGIES, volume 16, no. 4, 2012 (Abstracts)

A. Grakovski, A. Batenko, G. Berzins, I. Kabashkin, E. Petersons, V. Truhachov. Impact of the External Factors on the Measurement of Weight-In-Motion by Fibre Optic Sensor, *Computer Modelling and New Technologies,* vol. 16, no. 4, 2012, pp. 10–17.

The results of application of fibre-optic sensors for measuring the weight of moving vehicles (weight-in-motion – WIM) are discussed in the present study. The different factors affect the measurement accuracy of fibre-optic sensors: features installed in the roadbed, and the nonlinearity and the lag effect of the sensor, the temperature effect. The results of laboratory and field measurements using a fibre-optic sensor are presented as well as a load and inertial characteristics and their approximations obtained for fibre-optic sensor under the impact of various external factors (protective cover, temperature, contact area, and especially installation). It has been found that the final calibration of the sensor can be done individually only after it is installed in the pavement. We discuss the algorithms for linearization, methods of temperature and dynamic oscillations compensation of fibre-optic sensor's data for its use in the measurement of weight-in-motion.

Keywords: transport telematics, weight-in-motion (WIM), fibre optic sensors (FOS), sensor's sensitivity, measurement, calibration

V. Truhachov, A. Grakovski. Signal Simulation Fibre Optic Sensors Measuring Weightin Motion in the Basis of the Differential Equations, *Computer Modelling and New Technologies,* vol. 16, no. 4, 2012, pp. 18–24.

In the present study we are discussing the possibility of fiber optic sensor application for weighing road vehicles in motion (WIM – weight-in-motion). The various factors affecting the accuracy of fiber optic sensors measurement are considered to be: features of the installation in the roadway, the nonlinearity and inertia of the sensor, the thermal effect, the inertial force of the vibrating vehicle and the extremely short time of the load standing on the sensor. The impact of these factors on the accuracy of WIM systems were analyzed and tested by simulations and field tests. The aim of this work is to simulate the signal of fiber optic sensors in the basis of differential equations of a deformable wheel bearings, the identification of linkages with optoelectronic mechanical parameters and to find the mass of the vehicle by minimizing the discrepancy between the actual WIM-signal and the solution of the differential equation of oscillations of the wheel.

Keywords: transport telematics, vehicle detection, weight-in-motion (WIM), fibre optic sensors (FOS), stiffness of bracket and tire

P. Shakun, Yu. Sikerzhicky, M. Petrunina. Signal Processing of the Fiber Optic Sensors in the Complex Use of the Static and Dynamic Vehicle Weighing System, *Computer Modelling and New Technologies,* vol. 16, no. 4, 2012, pp. 25–32.

One of the dynamic weighing challenges is to recognize the overloaded vehicle in the traffic flow. In this article, it was shown the possibility of the signal processing in the dynamic weighing devices using the fibre optic sensors, in order to make the decision of the overloaded vehicle presence on the road. There also were proposed the processing algorithm of the data received from the output of the fibre optic sensor; as well as the requirements for the elements and the blocks of the algorithm were defined. There was also introduced the concept meaning of the reference system. As the reference system there was proposed the possibility to use the digital filter with the finite impulse response. The estimation method of the filters' weight coefficients was proposed.

Also, several tests of the algorithm were made for the vehicle identification with the reference load.

Keywords: dynamic weighing, digital data processing, system identification

Yu. Krasnitsky. Transient Response of a Small-Buried Seismic Sensor, *Computer Modelling and New Technologies,* vol. 16, no. 4, 2012, pp. 33–39.

A model of small-buried seismic sensor transient response excited by a car tyre interaction with asphalt-concrete road pavement is proposed. It is supposed that a seismic wave received by the sensor is the vertical component of surface Raleigh wave. The model is based on supposition that a tyre footprint is acceptable to consider as some array of point sources of these waves. The proper algorithms permit to vary different parameters of the array excitation, as to footprint dimensions, load distribution, motor car velocities and others. The set of Matlab codes for seismic transient pulses modelling and processing has been worked out.

Keywords: weigh-in-motion system, tyre footprint, impact, road pavement reaction, sensor response modelling

COMPUTER MODELLING and NEW TECHNOLOGIES, 16. sējums, Nr. 4, 2012 (Anotācijas)

A. Grakovskis, A. Batenko, Ģ. Bērziņš, I. Kabaškins, E. Pētersons, V. Truhačovs. Ārējo faktoru ietekme uz svars-kustībā mērījumu ar šķiedru optisko sensoru palīdzību, *Computer Modelling and New Technologies,* 16. sēj., Nr. 4, 2012, 10.–17. lpp.

Šajā pētījumā tiek apspriesta optisko šķiedru sensoru piemērošana braucošo transportlīdzekļu svaru mērīšanai (svars-kustībā – *angl.* Weight-in-motion (WIM)) un to rezultāti. Dažādi faktori ietekmē optisko šķiedru sensoru mērījumu precizitāti. Laboratorijas un lauka mērījumu rezultāti, izmantojot optisko šķiedru sensoru, arī tiek parādīti kā slodzes un inerces īpašības un to tuvinājumi, iegūti optisko šķiedru sensoriem dažādu ārēju faktoru (seguma, temperatūra, kontaktu laukums un, it sevišķi, instalācija) iespaidā. Ir konstatēts, ka sensora galīgā kalibrēšana var būt veikta individuāli tikai pēc tam, kad tas ir uzstādīts uz ietves. Autori izskata algoritmus linearizācijai, temperatūras metodes un optisko šķiedru sensora datu dinamisku svārstību kompensāciju to lietošanai svars-kustībā mērījumos.

Atslēgvārdi: transporta telemātika, svars-kustībā, šķiedru optikas sensori, sensora jutība, mērīšana, kalibrēšana

V. Truhačovs, A. Grakovskis. Optisko šķiedru sensoru signāla simulācija mērīšanai svars-kustībā, pamatojoties uz diferenciālvienādojumu, *Computer Modelling and New Technologies,* 16. sēj., Nr. 4, 2012, 18.–24. lpp.

Šajā pētījumā mēs apspriežam optisko šķiedru sensoru pieteikuma iespēju autotransporta līdzekļu kustībā (*WIM* – svars-kustībā) svēršanai. Dažādi faktori, kas ietekmē optisko šķiedru sensoru mērījumu precizitāti, tiek uzskatīti: uzstādīšanas iezīmes uz ceļa, sensora nelinearitāte un inerce, siltuma efekts, transportlīdzekļa vibrācijas inerciāls spēks un ļoti īss slodzes atrašanās laiks uz sensora. Šo faktoru ietekme uz *VIM* sistēmas precizitāti tika analizēta un pārbaudīta ar modelēšanas un lauka testiem. Šī darba mērķis ir simulēt šķiedru optikas sensoru signālu, pamatojoties uz deformējamo riteņu gultņu diferenciālvienādojumiem, saiknes ar optoelektroniskiem mehāniskiem parametriem identifikācija un noteikt transportlīdzekļa masu, samazinot neatbilstību starp faktisko *VIM* signālu, un riteņa svārstību diferenciālvienādojuma risinājums.

Atslēgvārdi: transporta telemātika, transportlīdzekļu detektēšana, svars-kustībā, šķiedru optikas sensori, kronšteinu un riepas stingrums

P. Šakuns, J. Sikeržickis, M. Petruņina. Šķiedru optisko sensoru signāla apstrādestatisko un dinamisko satiksmes līdzekļu svēršanas sistēmas kompleksā lietojumā, *Computer Modelling and New Technologies,* 16. sēj., Nr. 4, 2012, 25.–32. lpp.

Viens no dinamiskās svēršanas uzdevumiem ir atpazīt pārslogoto transportlīdzekli satiksmes plūsmā. Šajā rakstā ir parādīta signāla apstrādes iespēja dinamiskās svēršanas ierīcēs, izmantojot šķiedru optiskos sensorus, lai pieņemtu lēmumu par pārslogotā transportlīdzekļa klātbūtni uz ceļa. Rakstā arī tika piedāvāts saņemto datu no izejas šķiedru optiskā sensora apstrādes algoritms; kā arī tika noteiktas prasības elementiem un algoritma blokiem. Standarta sistēmas jēdziena nozīme arī tika ieviesta. Par standarta sistēmu tika ierosināta iespēja izmantot digitālo filtru ar galīgo impulsa reakciju. Filtru svara koeficientu novērtēšanas metode tika ierosināta.

Bez tam arī vairāki algoritmu testi tika veikti attiecībā uz transportlīdzekļa identifikāciju ar standarta slodzi.

Atslēgvārdi: dinamiskā svēršana, digitālo datu apstrāde, sistēmas identifikācija

J. Krasņitskis. Neliela ierakta seismiskā sensora pārejoša reakcija, *Computer Modelling and New Technologies,* 16. sēj., Nr. 4, 2012, 33.–39. lpp.

Rakstā ir izskatīta neliela ierakta seismiskā sensora modeļa pārejošā reakcija uz automašīnu riepu mijiedarbību ar asfalt-betona ceļa segumu. Ir paredzēts, ka seismiskais vilnis, ko saņem sensors, ir Raleigh viļņa virsmas vertikālā komponente. Modelis ir balstīts uz pieņēmumu, ka riepas nospiedumu ir pieņemami uzskatīt par šo viļņu punktveida avota masīvu. Pareizie algoritmi ļauj mainīt masīva uzbudinājuma dažādus parametrus, tādus kā nospiedumu izmēri, slodzes sadalījums, automašīnu ātrums, un citi. Rakstā ir izstrādāts Matlab kodu kopums seismisko pārejošo pulsāciju modelēšanai un apstrādei.

Atslēgvārdi: svēršana-kustībā sistēma, riepu nospiedums, ietekme, ceļa seguma reakcija, sensoru atbildes modelēšana

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