Title: New Sensors System for Monitoring of Traffic Load

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ABSTRACT

New methodology of measurement of traffic load characteristics is presented. The proposed approach is based on the concept of monitoring of strain development in deformable body (Load Detecting Device LDD) affected by the moving load.

It is planned to focus on identification of traffic load location, intensity, speed and shape using LDD deformable body (e.g. steel tube mounted below the pavement) equipped with the system of piezo-sensors.

The crucial point of this proposition is to develop technique for the inverse problem algorithm able to identify unknown parameters, as location of the load (truck wheel position), its intensity (depends on load of the truck), speed and steepness (depends on air pressure in tires) on the base of measured local strain development in sensor locations. Moreover, it is important to have an algorithm, efficient enough to perform in real time on the base of hardware data processing rather than with use of time-consuming computation.

INTRODUCTION

There are known technical systems performed to monitor Traffic Load. Weigh In motion (WIM) techniques have been developed to collect data for statistical purposes. Some results have been used for improvement of pavement managing systems, road transport analyses, detection of overloaded vehicles etc [2].

Nowadays most of WIM system are based on weighing detectors embedded in the pavement. Various kinds of sensors are used in measurements for example: piezoceramic cables and bars, piezoquartz bars, capacitive strips and mats strain gauge or load cells etc. WIM systems are sensitive to the excitation produced by car tire pressing on it. There are used several kinds of WIM systems like: bending plate,

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load cell, bridge WIM, piezoelectric sensors etc.
Most of the WIM systems have been designed in USA or western Europe. They are able to measure: vehicle gross weight, individual axle weight, vehicle class, vehicle length , wheel base , individual axle separation, vehicle speed [1]. They can also collect and send the data.
In USA WIM systems are classified into four types according to their speed range, data gathering capabilities and application. Type I is intended to collect traffic data for speed range 16 – 113 km/h, while type IV is mounted in weight enforcement stations and works for speed range 24 – 84 km/h [1]. Current WIM system are able to measure weight of the car with 10 % accuracy for (95% confidence level) [4] .
The cost of the WIM installation strongly depends on the type of the system . In USA the “ Initial budgetary equipment cost” is 20,500 $/lane for Kister system and 2,500 $/lane for Piezoelectric. But also installation of WIM system is costly. For Kister system “Initial budgetary installation cost” is 12,000 $/lane and 6,500 $/lane for Piezoelectric system [4]. In Germany full cost of new WIM system was 1.150.000 euro [5].

DESCRIPTION OF TESTING BENCH AND METODOLOGY OF MEASUREMENTS

Test bench has been built to develop an efficient algorithm.
The test bench includes a steel pipe supported at the ends (see figure 1). Piezoelectric actuator is used to generate the excitation. Two piezoelectric patches located symmetrically on surface of the pipe are used to measure the parameter of excitation.
Design of the stand enables us to put the actuator in few different positions along the test pipe. The electric signal of various values of an amplitude and period can be used to drive the actuator. Waveform of signal driving the actuator is shown in figure 2.

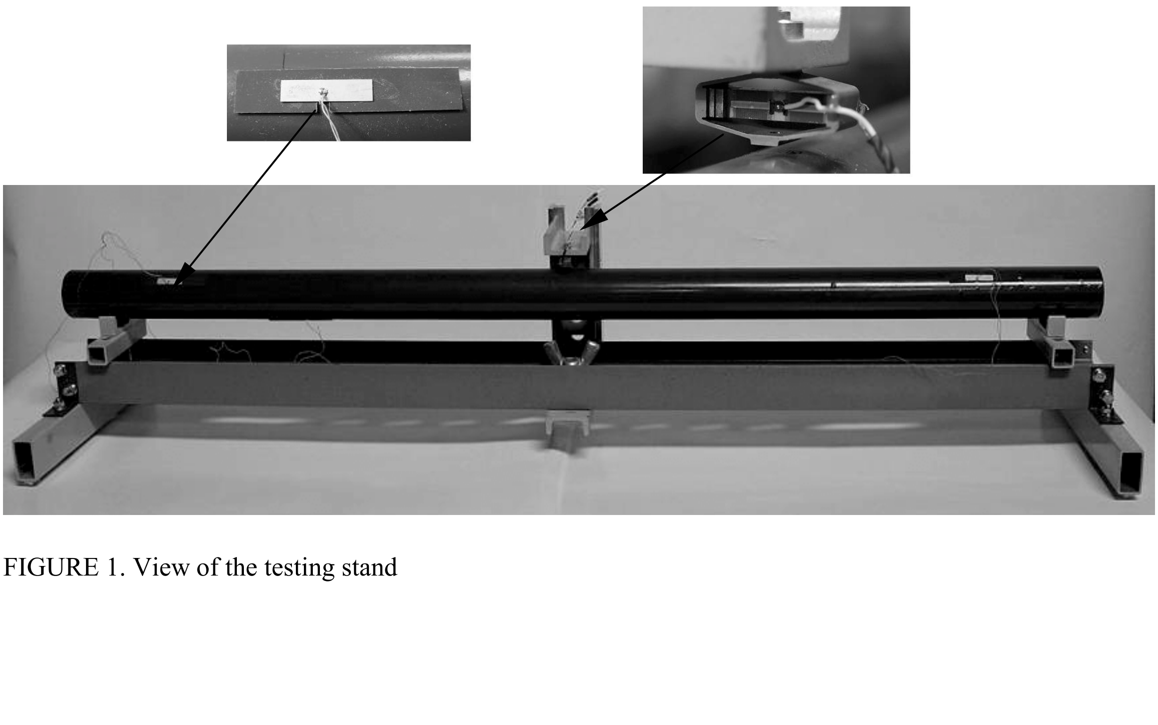

FIGURE 1. View of the testing stand

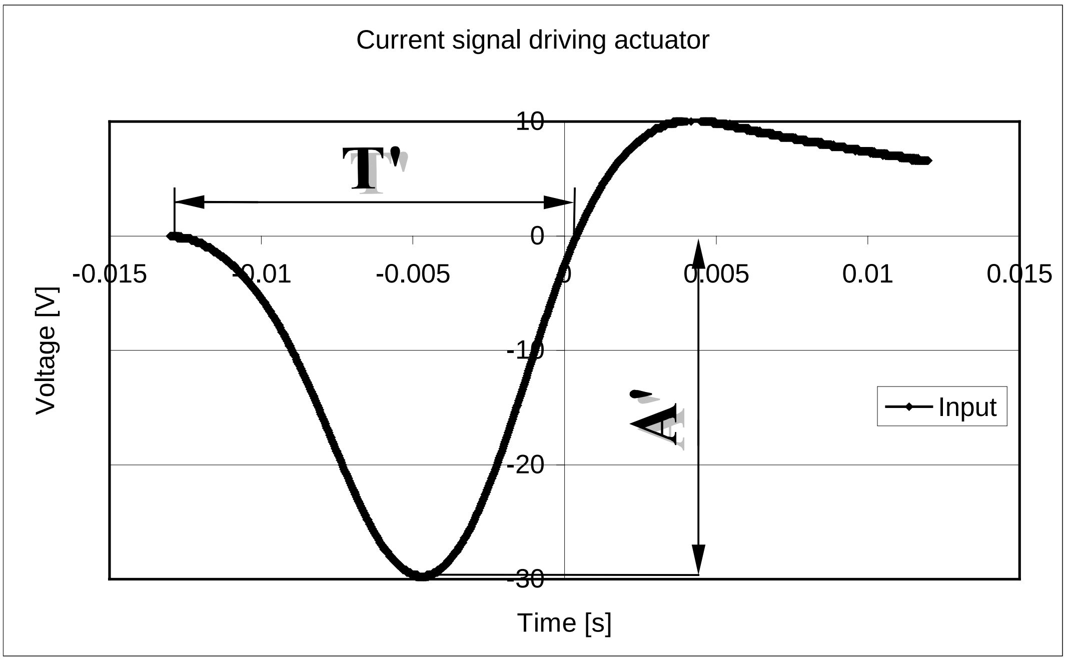

FIGURE 2. Waveform of current signal driving the actuator where:
A'- amplitude of signal driving the actuator,
T'- period of signal driving the actuator.

Sinusoidal signal is used to simulate tire force exerted by running car on the structure.
The parameters shown above have some physical meaning:
- period of signal can be equivalent to the speed of the car ,
- amplitude of signal can be equivalent to the weight of the car .

In real road conditions cars have different speed, weight and the position of the wheel on the road. We have to take into account these three factors while making the tests. That is why during experiment we put actuator in the various position and used excitation with various value of period and amplitude.
When the pipe is bent the current signal is produced by piezoelectric sensors.
On the basis of the signal generated by piezoelectric patch we can determine the following parameters: T – the period of sinus-like measured signal excited by moving wheel, A' – the amplitude of this signal. Applying two sensors located symmetrically with respect to supports of the deformable body, let us use symbol *l* denoting measurements coming from the left sensor and the symbol *r* denoting measurements coming from the right sensor
Sample signals received from the piezoelectric patch are shown on Figure 3.

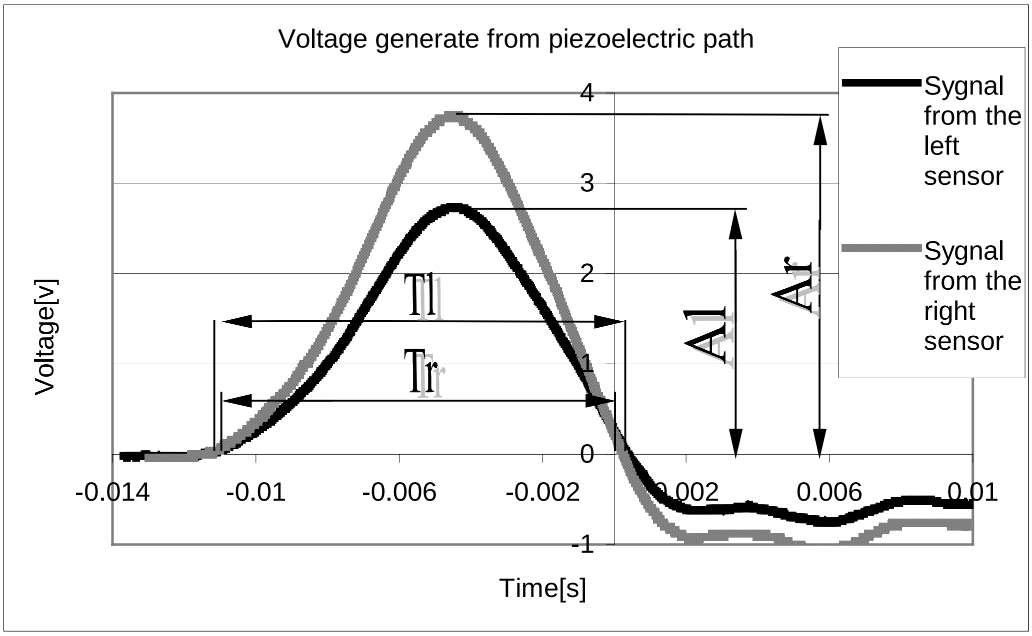

FIGURE 3. Signal produced by the sensor mounted on the pipe where:
Al- amplitude of the signal produced by left piezo-sensor,
Ar- amplitude of the signal produced by right piezo-sensor,
Tl- period of signal produced by left piezo-sensor,
Tr- period of signal produced by right piezo-sensor.

ALGORITHM OF LOAD CALCULATIONS

The aim of the algorithm is to identify the excitation bending the pipe.
In real road conditions cars have different technical and motion parameters that is why algorithm should be sensitive to:

- position of tire forces pressing on the structures,
- speed of the car,
- weight of the car.

Some simplifications have been made while creating the algorithm. Linear dependence of response on the excitation is assumed. This can be easily justified by the fact that piezoelectric material has linear characteristics and the deformable structure undergoes only small deformations.
Correctness of this simplification has been checked experimentally. Results of the test are shown in Figure 4.

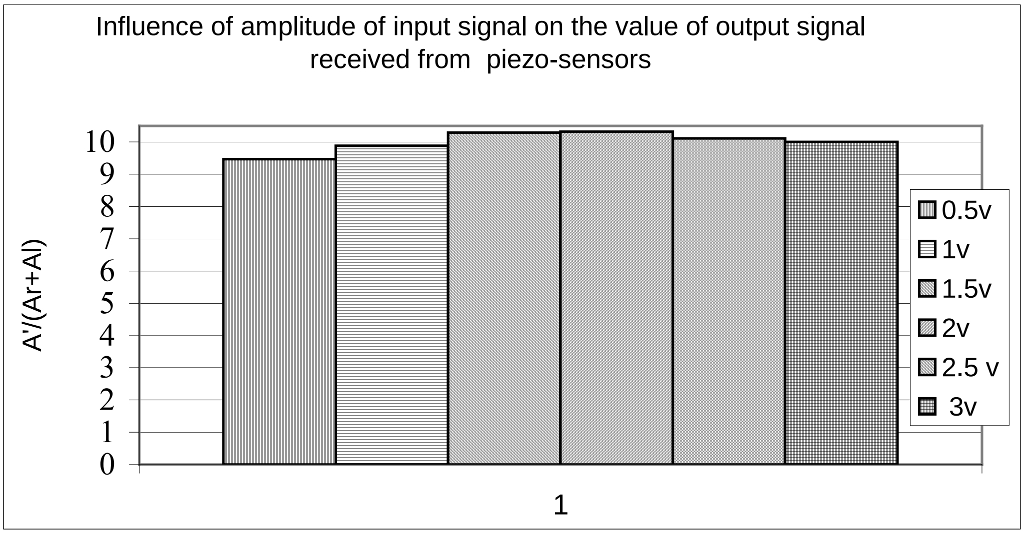

FIGURE 4. Ratio of the amplitude of the input signal to the sum of the signal amplitudes received from piezo –sensors where different values of excitation signal are used

In first step the algorithm should recognize where the excitation is located on our structure. Position of load X' can be determined by use of the following formula:

$$X' = \frac{(Al - Ar)}{(Al + Ar)} \qquad (1)$$

where, if the load is applied in the middle of the tube, then X'= 0. If the load is applied closer to the left senor X'>0 and if it is applied closer to the right senor, X'<0. From the function *x*=f(X') (determined experimentally) we can get the real position of the load.

Results obtained experimentally after applying equation (1) are presented in figure 5.

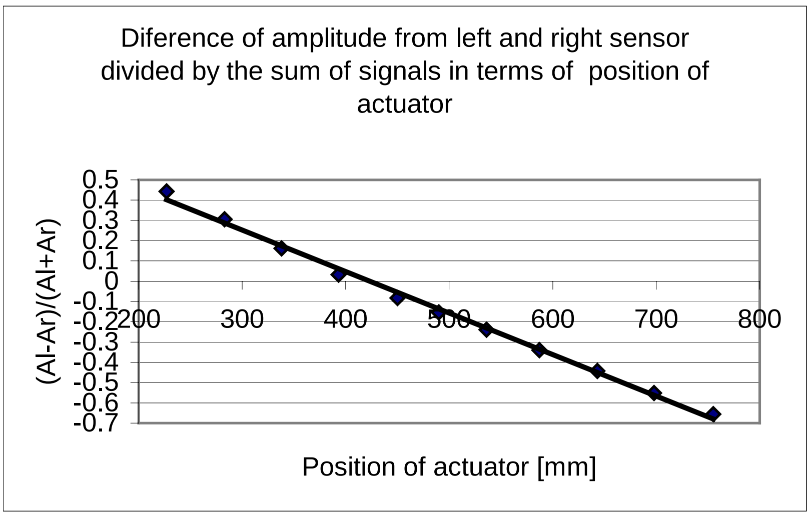

FIGURE 5. Value (Al – Ar)/(Al + Ar) in terms of position of an actuator

The time of lasting of the excitation *T*' can be calculated from the formula (2). Time strongly depends on the speed of the car, so after measuring it we can preliminary estimate speed of the car.

$$T' = \frac{(Tl + Tr)}{2} \qquad (2)$$

The dependence between position, time of excitation and ratio of amplitude of input signal to amplitude of output signal can be obtained experimentally or numerically.
FE model of real prototype of the road testing stand which will be tested soon is presented in figure 6. The vectors of forces pressing on a plate simulate the influence the car tire on the structure.
Up to now algorithm has been checked for result obtained experimentally in the laboratory testing stand. So the relationships between position, time of excitation and ratio of amplitude of input signal to amplitude of output signal after approximation for result obtained experimentally are presented in figure 7.

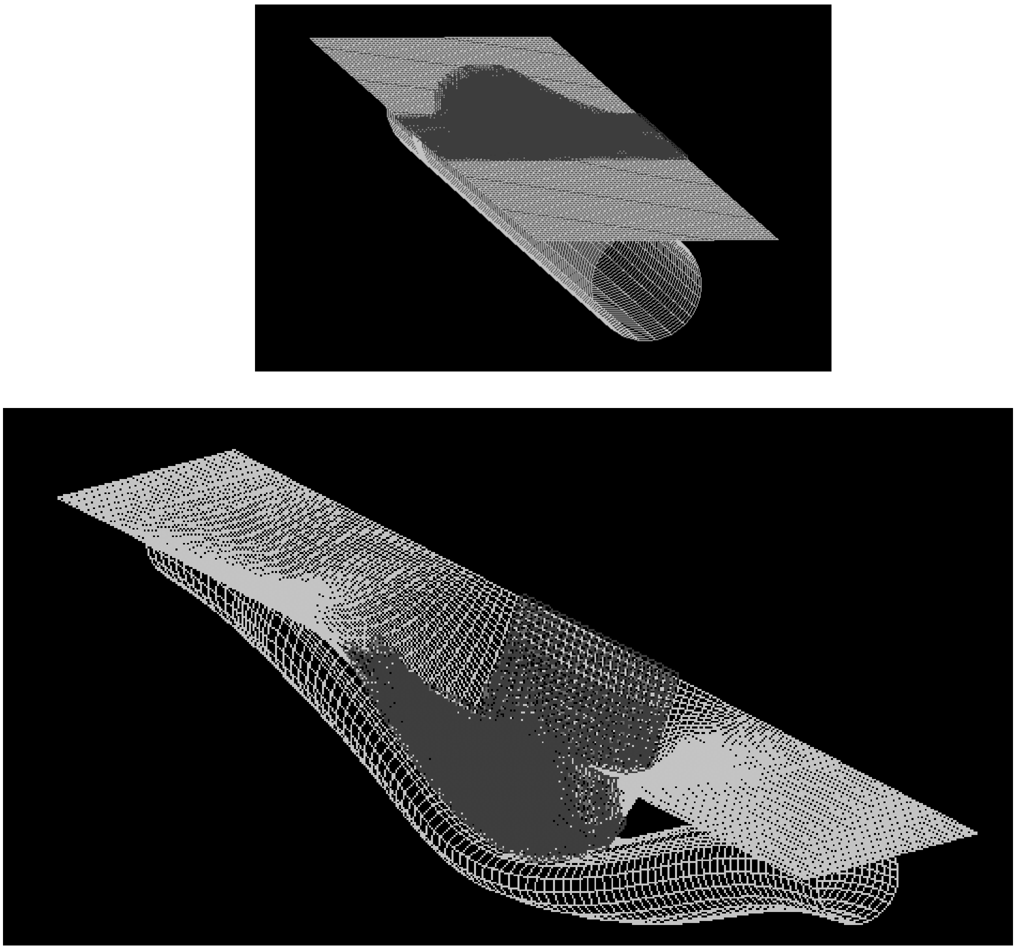

FIGURE 6. FE model of the prototype of LDD

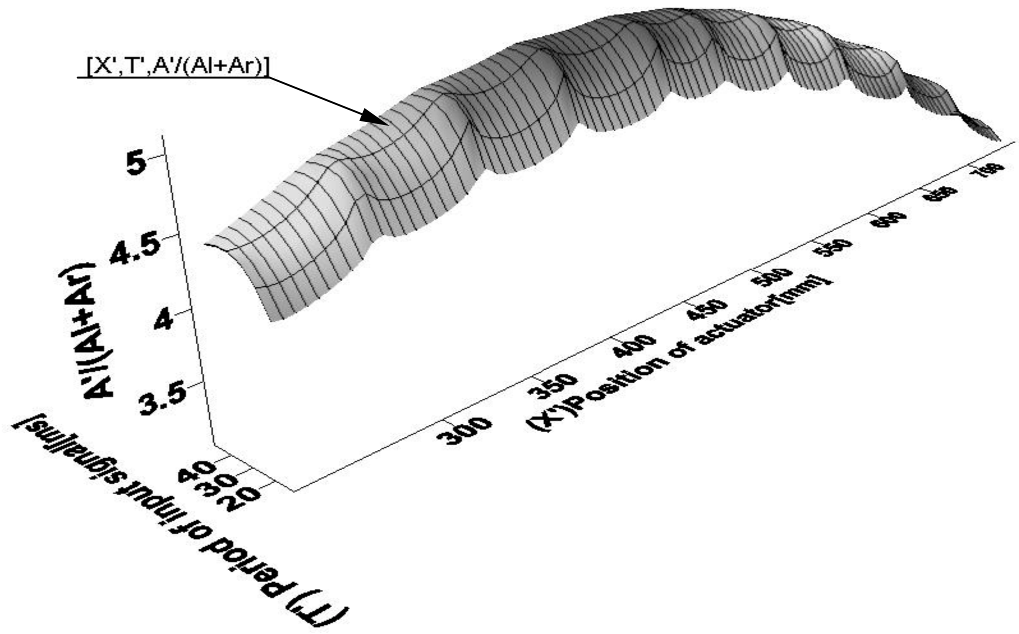

FIGURE 7. Surface used for determination of the input amplitude value

Finally if we determine the position of excitation and time of excitation we can obtain the value of third unknown parameter K given by the formula (3).

$$K(X',T') = \frac{A'}{(Al + Ar)} \tag{3}$$

The real value of parameter K (X,T)can be easily read from figure 7.
Finally, the load intensity *A'* affecting LDD can be calculated from the formula (4).

$$A' = (Al + Ar) \cdot K(X,T) \tag{4}$$

CONCLUTIONS

In conclusion, the relations described above can be useful in the formulation of a simple algorithm leading to the determination of the searched parameters T', X', A' identifying load excitations. Nevertheless, precise numerical analysis of the complex problem will be undertaken in order to estimate errors corresponding to the simplified models. As well experimentally and numerically obtained result should be checked and verified during field test.

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