New Sensor System for the Monitoring of Traffic Load

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1. Introduction

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

The aim of the study is to focus on the identification of traffic load location, intensity, speed and shape using the 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 a technique for the inverse problem algorithm able to identify unknown parameters, such as location of the load (truck wheel position), its intensity (depends on the load of the truck), speed and steepness (depends on the 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 the use of time-consuming computation.

2. Description of the testing bench and methodology of measurements

The test bench includes the steel pipe supported at the ends (see Photo1). A Piezoelectric actuator is used to generate the load excitation. Two piezoelectric patches located symmetrically on the surface of the pipe are used to measure the structural response.

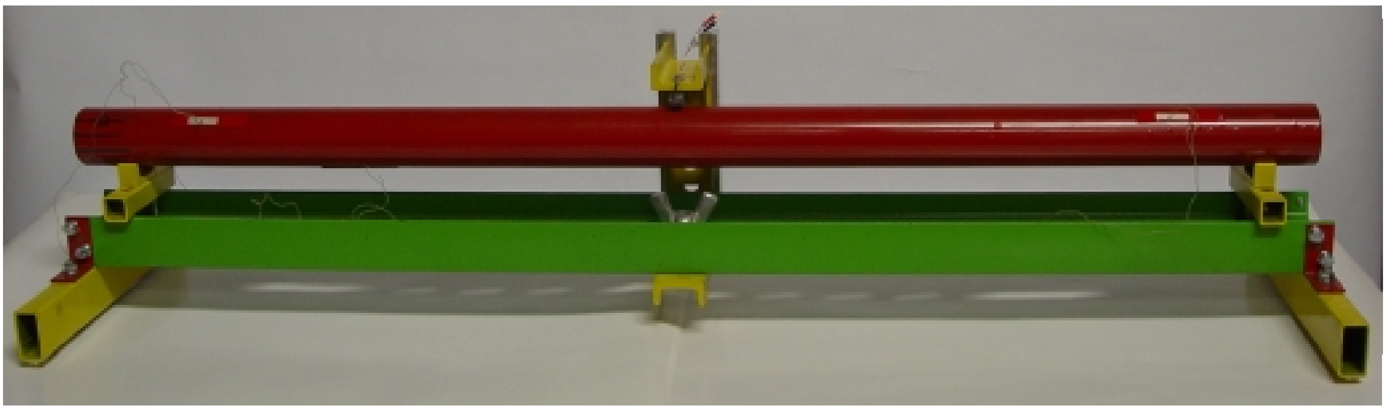


Photo 1 View of the testing stand

The design of the stand enables us to put the actuator in a few different positions along the test pipe. The electric signal of various values of the amplitude and the period can be used to drive the actuator. A half sinusoidal signal is used to simulate excitation caused by a moving car.

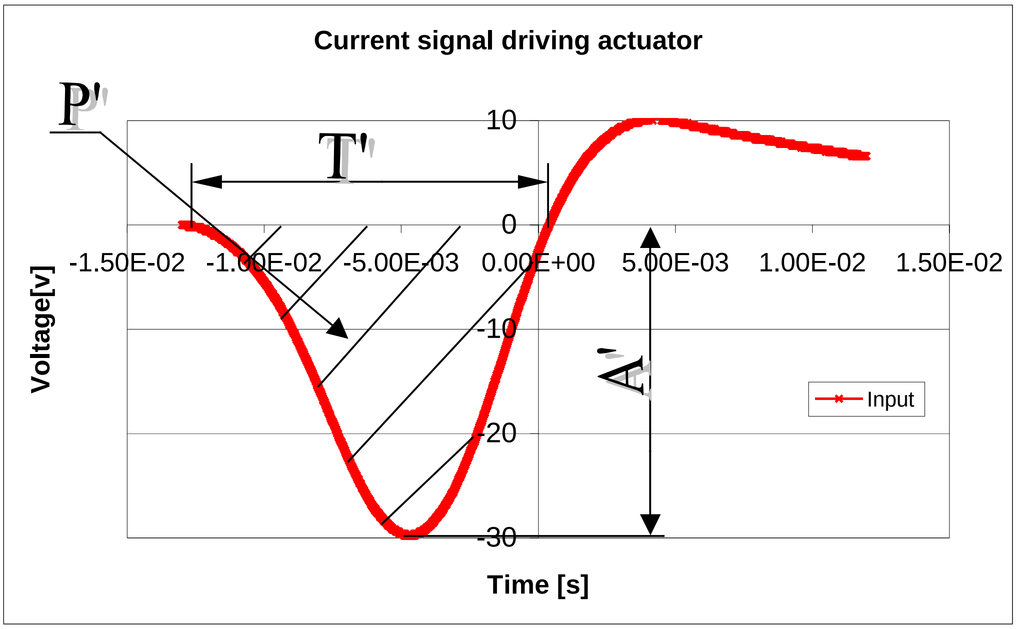


Fig.1 Waveform of current signal driving the actuator:
A'- amplitude of signal driving the actuator, T'- period of signal driving the actuator,
P'- area under the curve of voltage in time function.

The parameters shown above have some physical meanings:

- The area under the curve can be correlated with the weight transmitted via the car wheel,
- The period of the signal can be correlated with the speed of the car ,
- The amplitude of the signal can be correlated (together with P')with the stiffness of the wheel tire.

In real road conditions cars have different speed, weight and position of the wheel on the road. We have to take into account these three factors while making the tests. When the pipe is deformed piezoelectric sensors produce the signal. Sample signal received from the piezoelectric patch is shown in Fig.2.

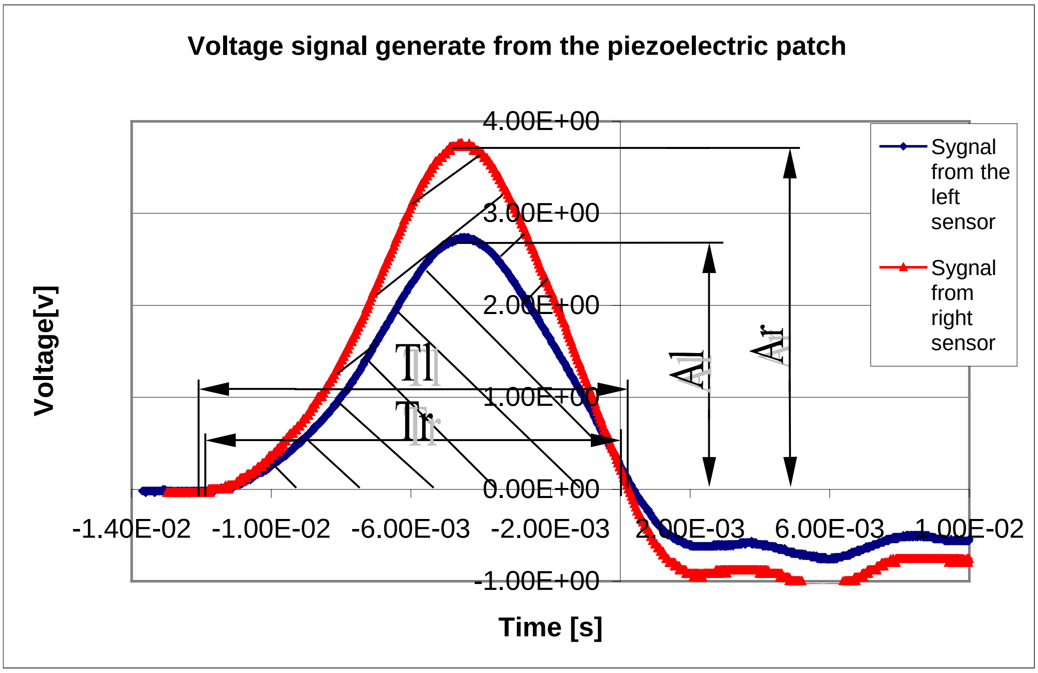


Fig. 2 Signal produced by the sensor mounted on the pipe:
Al- amplitude of the signal produced by the left piezo-sensor, Ar- amplitude of the signal produced by the right piezo-sensor, Tl- period of signal produced by the left piezo-sensor, Tr- period of signal produced by the right piezo-sensor, Pl- area under the curve of voltage in time function (signal generated from the left piezo-sensor), Pr- area under the curve of voltage in time function (signal generated from the right piezo-sensor). (cf.Fig.5).

When we put the actuator in the middle of the pipe we can expect the same signal from the two piezoelectric sensors, because they are identical and their position is symmetric. However, the collected data are not symmetric (due to various inaccuracies – cf.Fig.3). This observed mismatch can be partially corrected via an additional tuning coefficient X (Fig. 4).

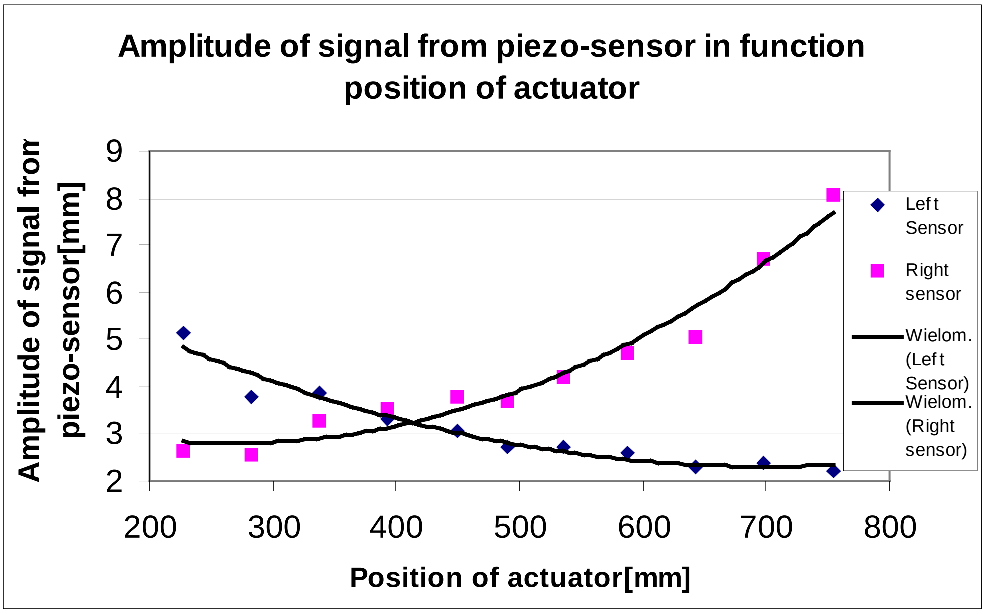


Fig.3 Measured signal amplitudes in terms of actuator positions

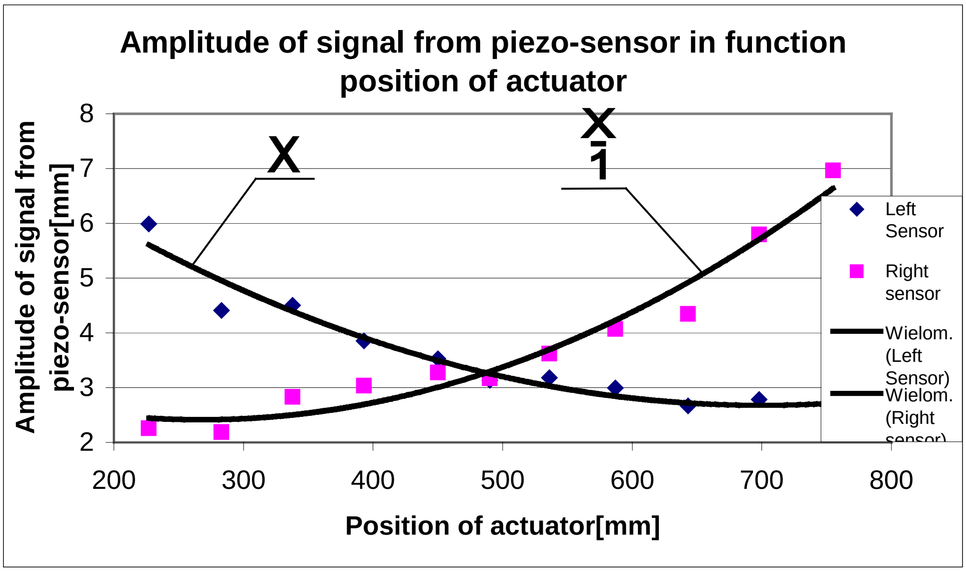


Fig.4 Scaled signal amplitudes in terms of actuator positions

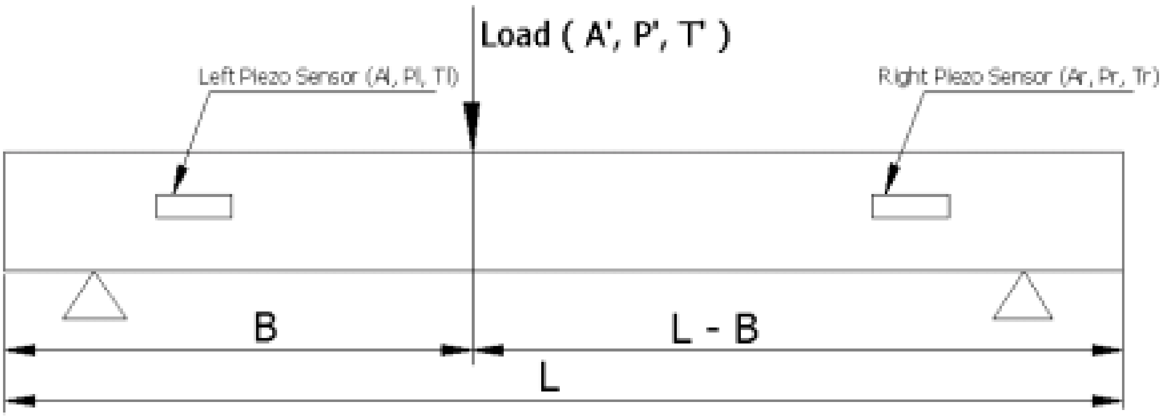
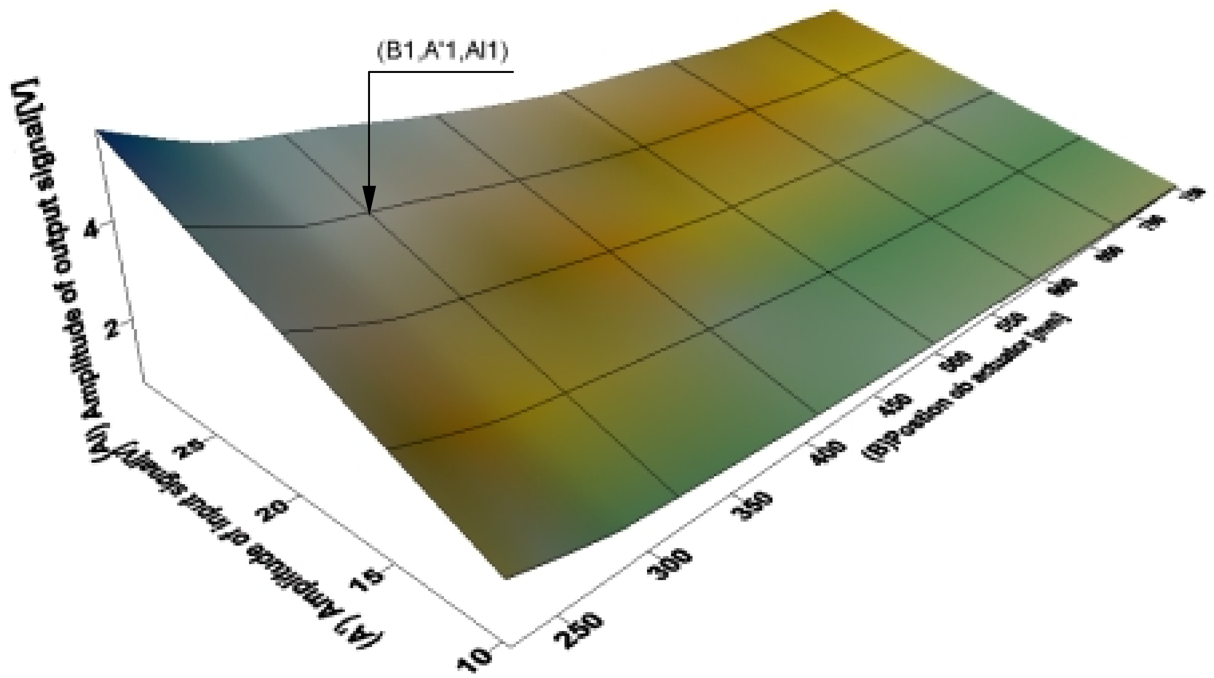


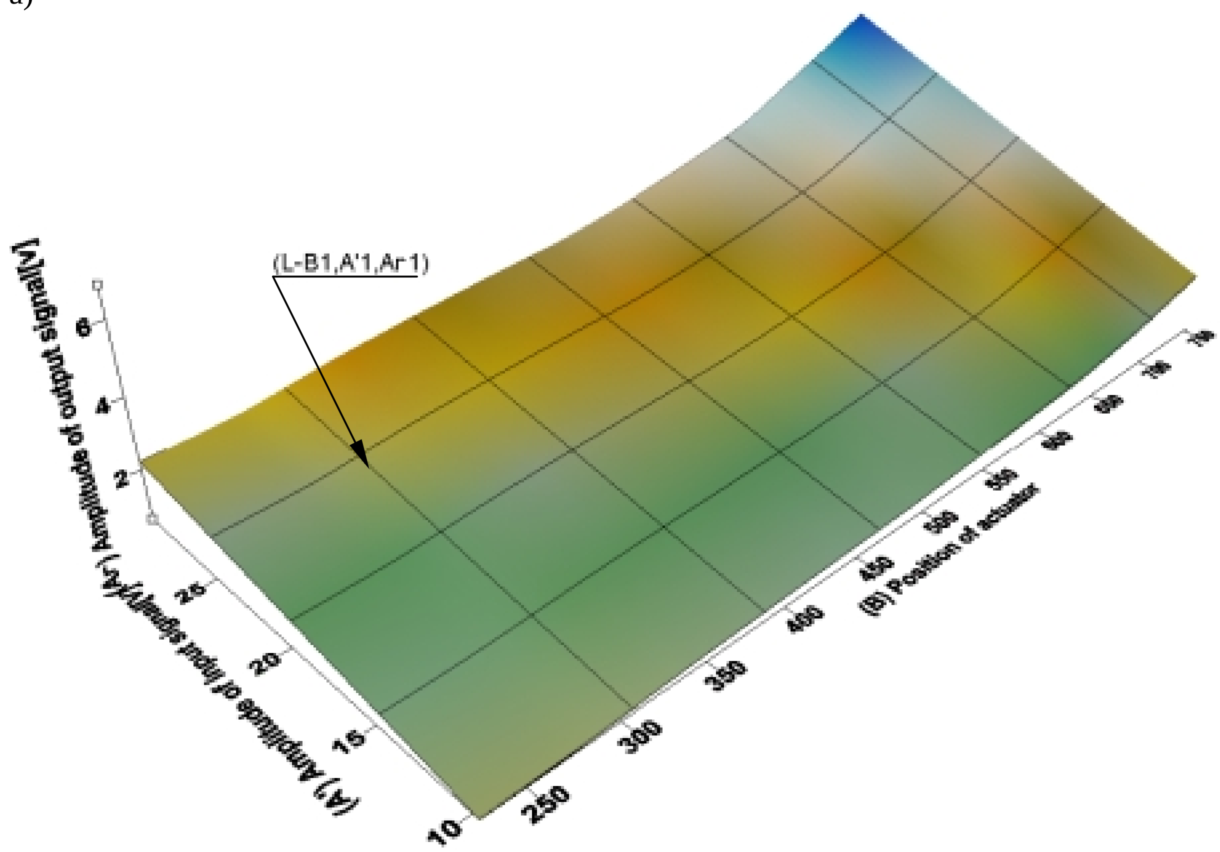
Fig.5 Dimensions of the test stand:
L- length of the pipe , B- distance between the left edge of pipe and the actuator

3. Load identification

Measured responses to various amplitudes of excitation are shown in Fig.6, where quasi-linear dependence Al/A' and Ar/A' can be observed.



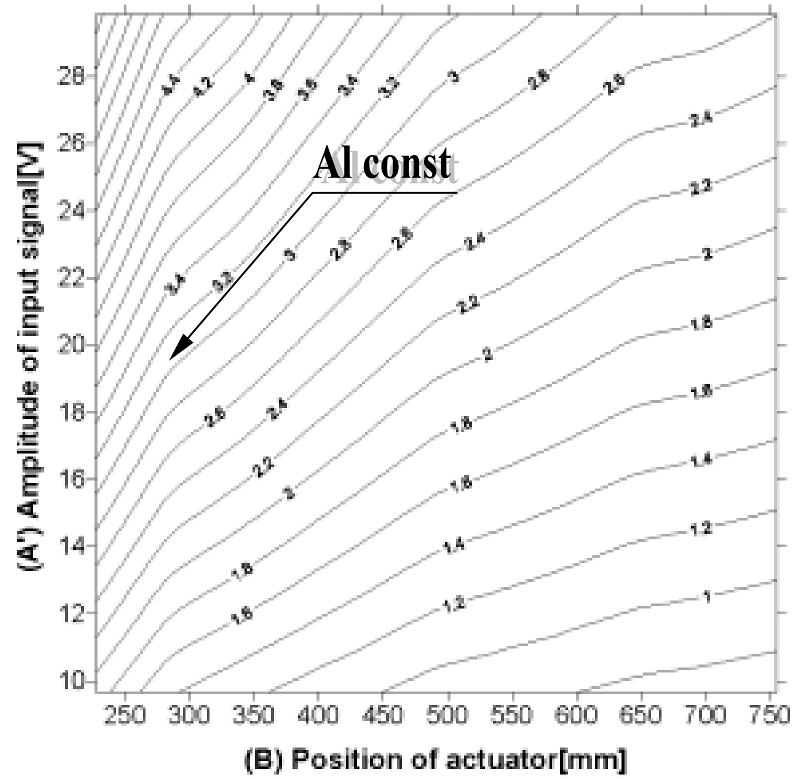
a)



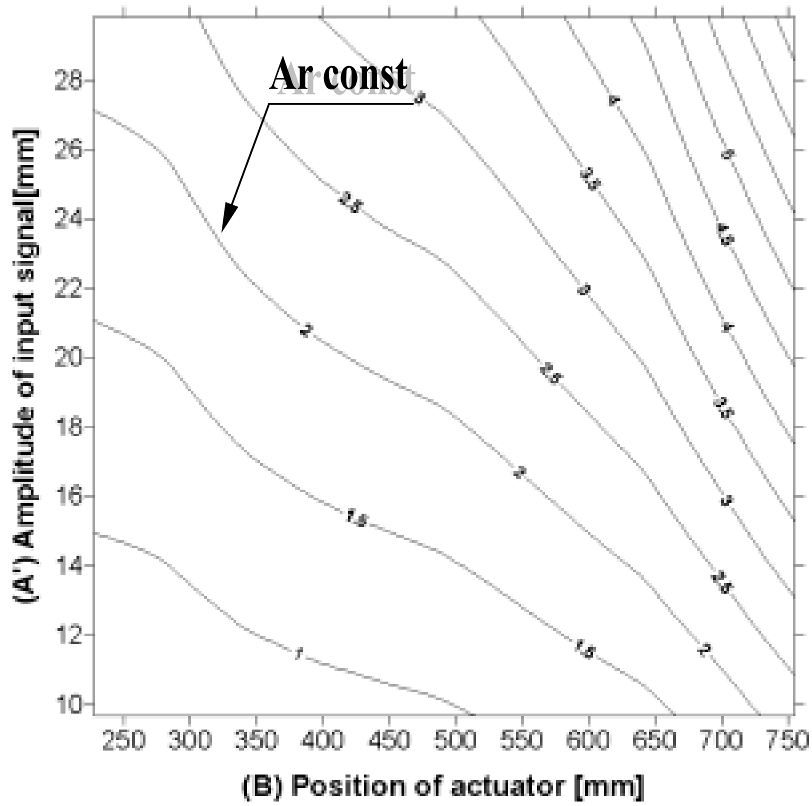
b)

Fig.6 Measured responses to various amplitudes of excitation
a) the left sensor surface b) the right sensor surface

Using horizontal projections of surfaces shown in Fig.6 the contour lines exposed in Fig.7 can be obtained.



a)



b)

Fig.7. Horizontal projections of the surfaces from Fig.6

a) the left sensor surface contour lines, b) the right sensor surface contour lines

Heaving measurements of the current amplitude of signals produced by left (A_1) and right sensor (A_r) one can find the relevant contours on the above graphs. An intersection point of these two curves will be identified by two coordinates: B' - the position of the actuator and A' - the amplitude of the input signal driving the actuator (see Fig. 8).

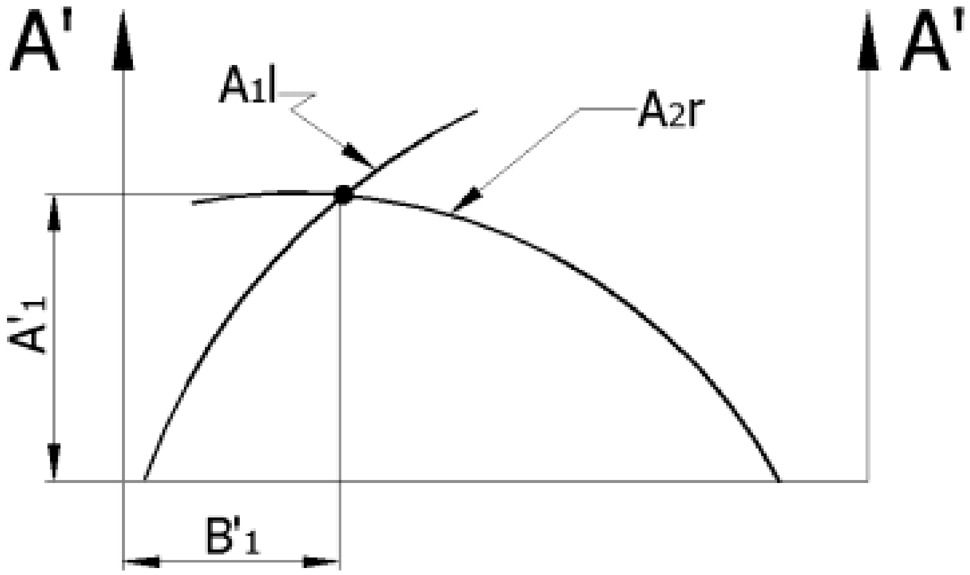


Fig.8 Determination of the input signal amplitude A' and the position B'

It can be observed that measurements *Tl* and *Tr* are close to each other and the following formula determining the period of excitation can be proposed:

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

4. Modified approach to load identification

An almost linear response of the system to changeable amplitudes of the input signal (Fig. 9) can be observed.

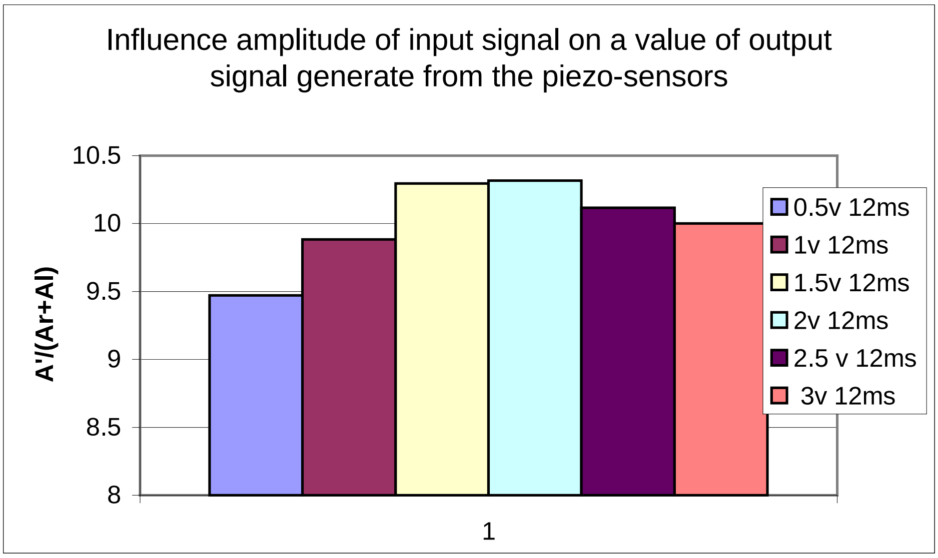


Fig.9 Proportion between the amplitude of the input signal and the sum of the signal amplitudes generated from piezo –sensors

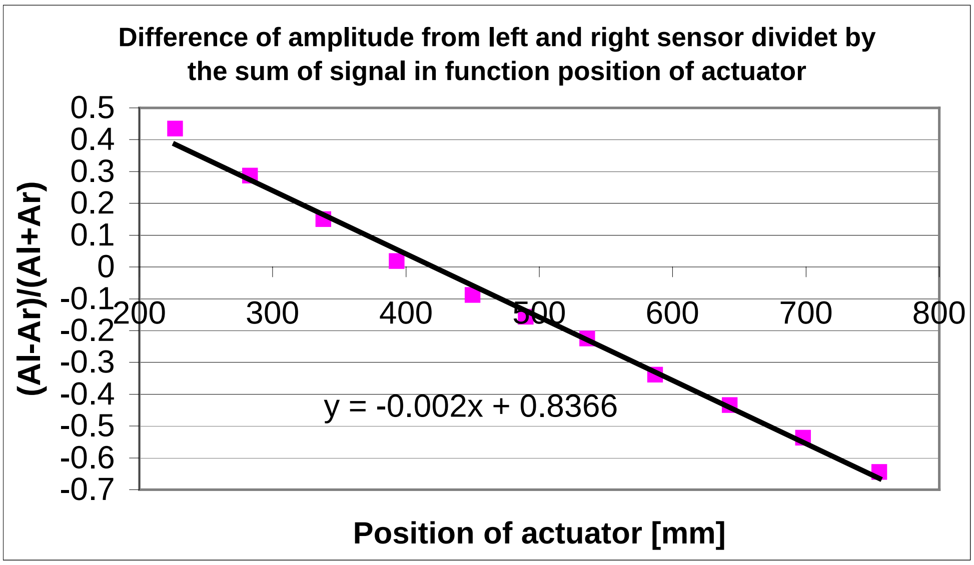


Figure 10. Value (Al – Ar)/(Al + Ar) in terms of position of the actuator

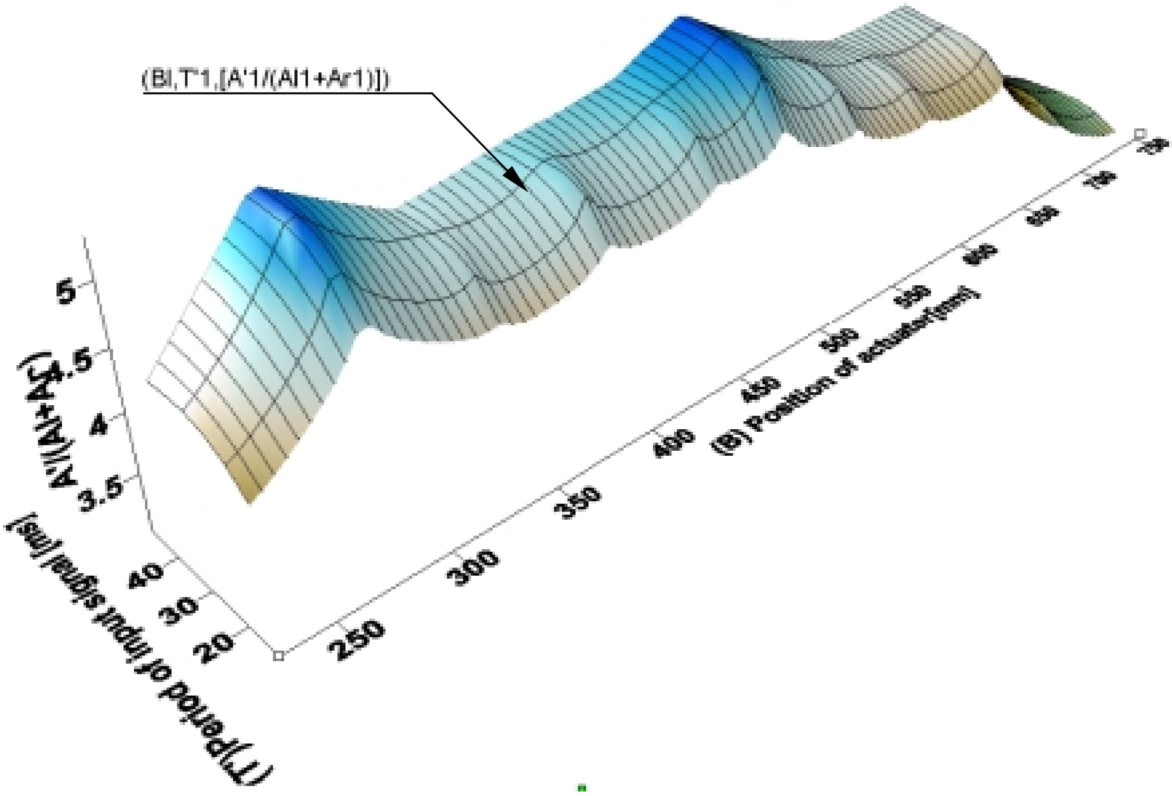


Fig. 11 Surface used for determination of the input amplitude A'

In consequence, the line demonstrated in Fig.10 depicting the following ratio: (Al-Ar)/(Al+Ar) can be used for identification of the actuator position B'. Then, having the period of excitation *T'* determined as above, the unknown input amplitude A' can be determined from the surface obtained by interpolation of measurement points (drawn in Fig. 11).Using more sophisticated approximation one can obtain the surface demonstrated in Fig.12.

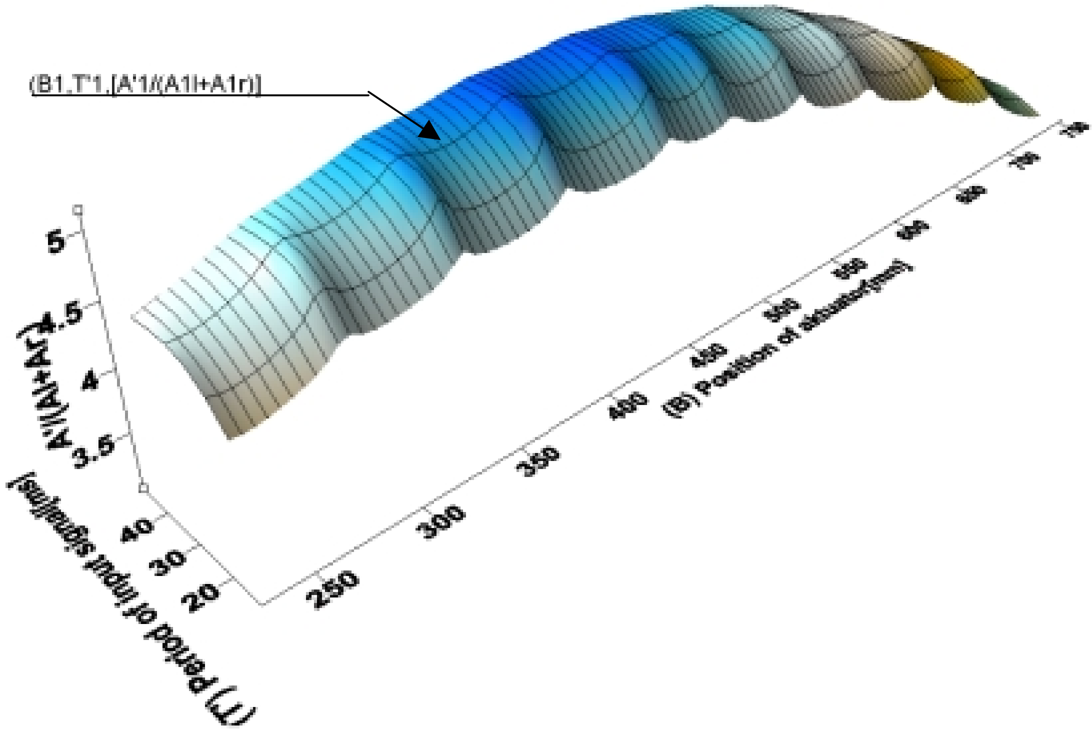


Fig. 12 Surface used for determination of the input amplitude A' (after the approximation)

It has been shown that it is possible to find the position of the input load B and the value of period T. Then, we can find the value of the third unknown parameter (Z=A'/(Al+Ar)). Consequently, knowing the signal values received from sensors we can obtain the amplitude of the input signal: A'= Z(Al+Ar).

In conclusion, the relations described above can be useful in the formulation of a simple algorithm (two optional algorithms) leading to the determination of the searched parameters T', B', A' identifying loading impacts. Nevertheless, precise numerical analysis of the complex problem will be undertaken in order to estimate errors corresponding to the simplified, decomposed models.