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Cover page

Title: *Real Time Dynamic Mass Identification*

Authors: *Krzysztof Sekuła, Grzegorz Mikułowski, Jan Holnicki-Szulc*

ABSTRACT

The objective of this paper is to present a real-time technique for mass and load history identification in the case of an external mass affecting a structure. Two strategies of identification are considered depending on character of the excitation.

When the structure surface is subjected to a *moving load* a methodology based on monitoring of strain development in the structure is applied. A beam with built-in piezoelectric sensors has been used in the experimental set-up. In this case an inverse problem is solved. From a previously prepared solution map (containing dynamic responses of the structure to different excitation scenarios) the most similar solution is chosen by the minimization of the difference between saved and actually measured response. In this way the initial load value is determined.

The second concept of the mass identification can be used when an *impact load* is considered. Excitation comes from a free-falling mass impacting the so-called Adaptive Impact Absorption (AIA) System equipped with Real Time Impact Monitoring Sensors (RIM). In this case the identification technique is based on monitoring of force and acceleration observed during random impacts on AIA. The main objective is to predict the impact load parameters in real-time. To this end the analysis of local dynamic response should be performed fast enough to feed up the AIA.

INTRODUCTION

Mass identification is one of the oldest known measurements [1]. At the very beginning the mass identification was performed by the comparison of an unknown mass with the known standard. Thereafter, spring scales were applied, which is probably the least expensive device for making mass measurements statically [1]. Nowadays, for mass and load identification the electrical methods are used. The methodology is mainly based on the force or strain measurements in deformable body. Many kinds of sensors are applied in this application, namely: strain gages, load cells, piezoelectric sensors, and fiber optics [2, 3, 4].

Institute of Fundamental Technological Research, Polish Academy of Sciences
Swietokrzyska 21, 00-049 Warsaw Poland e-mail:(ksekula | gmikulow | holnicki)
@ippt.gov.pl , web page: <http://smart.ippt.gov.pl/>

When a static or quasi-static load is considered the identification is usually easier to perform. However, the level of difficulty increases drastically in the case of dynamic excitation. Many difficulties tend to appear especially in the case of impact loads, mainly due to short duration of the phenomena.

Two strategies of load identification are considered depending on the character of applied excitation. In the first case a moving loads' excitation is analyzed. The second one concerns the impact load excitation and this case is the continuation of the research presented in [5].

LABOLATORY TESTING STAND (moving loads analysis)

The motivation for building the testing stand was to perform a feasibility study of utilizing piezoelectric sensors as load detectors and to develop an efficient load identification algorithm.

The test bench included an aluminium cantilever beam with distributed four piezoelectric sensors. Each sensor was 25 mm long by 6 mm wide and 0.2 mm thick (see Fig. 1. b). The shape and dimensions of the beam were analogical as in case of a load cell model 1042, which is offered by Vishay Company. This kind of load cell can be used in weighting devices and are installed in scales produced by the biggest manufacturer of electronic weighting equipment in Poland RADWAG [6].

The experimental set-up consists of a small “ramp” which is used to speed-up the weighted object (in the case of the experiment: billiard ball). During the tests two different billiard balls (120 g and 210 g) were used. They were run over the plate fixed to the cantilever beam. The design of the stand allows the “ramp” to be put in different angular positions in order to obtain various speeds of the weighted objects. The ball was tracked in order to ensure reproducible ball movement during each experiment trial. In order to eliminate the impact effects an additional part of the ramp had been inserted between the slope and the measuring unit, which enabled the ball to run softly onto the sensing beam. The surface of the testing stand was covered with a rubber sheet in order to reduce the micro impact effects caused by the rolling ball.

The tests were conducted with two billiard balls of different masses, which enabled the analysis of weight influence on the device. The sensitivity of acquired signals to the speed of the weighted object and its relative position between the side edges of the sensing plate was also analyzed.

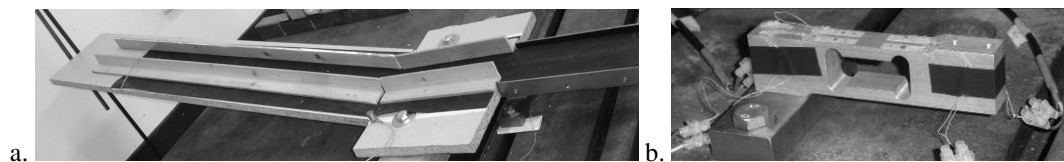


Figure 1. Testing stand: a. general view, b. cantilever beam with distributed piezoelectric sensors

Signal conditioning

The data acquisition set-up enabled to obtain real time measurements of signal generated from the four piezoelectric sensors used during the experiment. An additional accelerometer was used as a measurement trigger, which detected the impact of the ball to the flat part of the stand.

In Fig. 2.a an example of the measured signal generated by piezoelectric sensor is presented. Because of the character of the applied excitation and the type of used transducers the acquired signals included a high frequency “noise” component. In order to reduce it and to make the analysis easier a low pass (0-8 Hz) Butterworth filter was introduced. Results of the conditioning are presented in Fig. 2.b.

Finite element model of testing stand

A finite element model of the tested stand was built, see Fig. 3. In FEM two elements of the stand (aluminium cantilever beam, steel top plate) were modelled. The fixed connection between these two parts was simulated. The assumed boundary conditions were similar to that of the laboratory model. In the testing stand the lower surface of the beam was screwed to the foundation plate (see Fig. 1.b), hence this surface in the FEM has all six degrees of freedom fixed.

The influence of the billiard ball running over the plate was modelled by a set of force vectors moving over the simulated structure. The vectors covered a small rectangular area of approx. 2 cm^2 . In order to obtain comparable results from both models (numerical and experimental) the simulated load was moved in each step of the analysis.

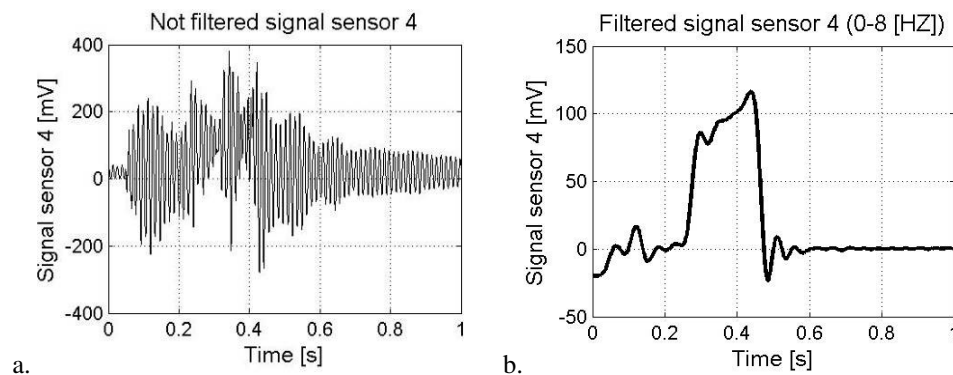


Figure 2. Signal produced by the piezoelectric sensor a. not filtered, b filtered

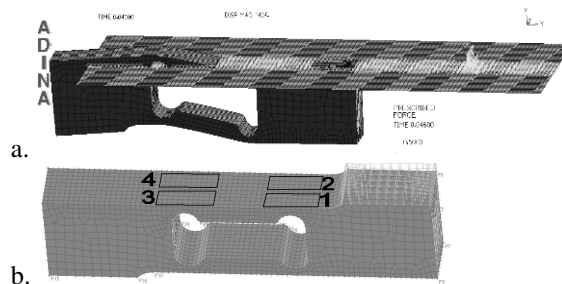


Figure 3. FEM of the testing stand; a. general view, b. distribution of modelled sensors

Four piezoelectric sensors were modeled in FEM. The adapted methodology of modeling was presented in [7,8]. Location of the modeled piezoelectric patches was the same as in the case of the laboratory model, see Fig. 3.b.

Laboratory and numerical results

Numerical analysis included the same range of tests as the laboratory research mentioned above. Verification by means of comparison of the results from FEM and from the laboratory experiment was conducted. The similarity of the obtained results is satisfactory, which is illustrated in Fig. 4.

The experiments and numerical tests enabled to draw the conclusion about linearity of the phenomena. The values of the signals generated by the piezoelectric sensors were directly proportional to the weight of the object. This can be easily explained by the fact that piezoelectric material has linear properties [9] and the deformable structure undergoes only small deformations. The sensitivity of the acquired signals on the speed of the weighted object and on its relative position between the side edges of the sensing plate was analyzed, see Fig.5.

Fig. 5 a. shows the amplitude ratio of the signal from first to the signal from the second sensor in relation to the ball position. Fig. 5 b. illustrates the amplitude signals in relation to the ball speed. In this case the similarity between numerical and experimental results was not obtained. It may have its origins in the data acquisition setup properties rather than the character of the phenomena.

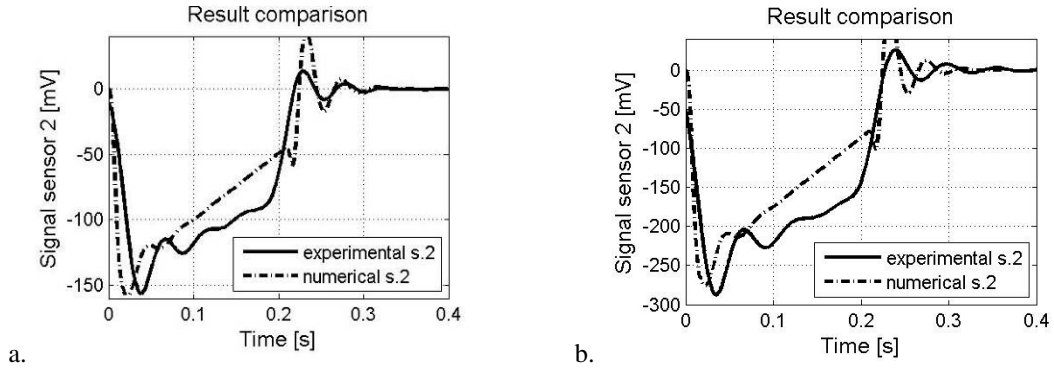


Figure 4 The experimental and numerical results: a. smaller ball (120g), b. bigger ball (210g)

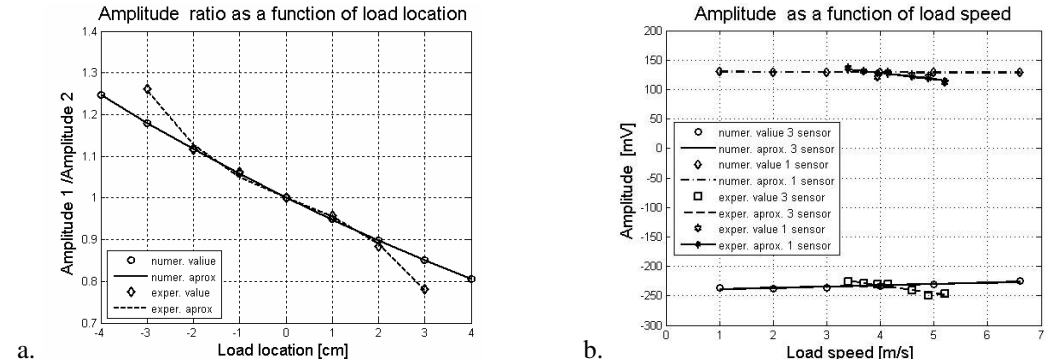


Figure 5 Sensitivity analysis (numerical and experimental); a. amplitude ratio in terms of ball position, b. amplitude signal from sensor 1 and 3 in terms of ball speed.

Algorithm of load calculations

An algorithm of load identification should take into consideration the speed and the position of the weighted object. It can be assumed that the dependence between the excitation and the response of the sensors is linear.

The methodology of load identification is based on an inverse problem solution. The solution map (storing dynamic responses to different excitation scenarios) for the considered structure should be prepared.

In the first step the algorithm recognizes the place where the excitation was located. For this purpose a 2D interpolation procedure can be applied, which uses a proportion between signals obtained from left and right hand side sensors on the beam. Next the speed of the weighted object must be detected and the process can be based on the duration of the measured signal. Finally, when the position and the speed of excitation are known the real value of the load can be obtained by means of a scaling factor. The scaling factor covers all signal fluctuations coming from various velocities and positions of the weighted object. The factor should be determined by means of 3D interpolation procedure in the range of the existing solution map. The algorithm was presented in detail in [8, 10].

DYNAMIC MASS IDENTIFICATION UNDER IMPACT LOADING

In order to perform the feasibility study of a real time dynamic mass identification technique a drop testing stand was used. The main objective for the study was determination of the time delays in the mass identification procedure, when we assume that the process is being performed after the beginning of the impact phenomena. The detected mass value can be used for the impact energy determination if the velocity of the falling mass was also monitored. Having the mass and velocity of the monitored object determined before the impact force reached its maximum value, it would be reasonable to apply a methodology for feed up an adaptive impact absorption system operating in real time. The objective of the presented research was to give an answer to the following question: How fast we are able to perform a mass identification after the beginning of an impact phenomenon?

Analytical model

The considered concept of the falling mass identification was analysed analytically on a simple 2 DoF model (see Fig.6a). The parameters of the model were taken close to the values present in the experimental model. The analysis via MATLAB software allowed coming to conclusion that it is feasible to identify the mass on the basis of its acceleration and impact force. The numerical experiment showed that the mass value is readable after 1 – 2 ms after impact instant (Fig. 6b) in case of concluding on the basis of mass acceleration and taking into account an inertia of the system.

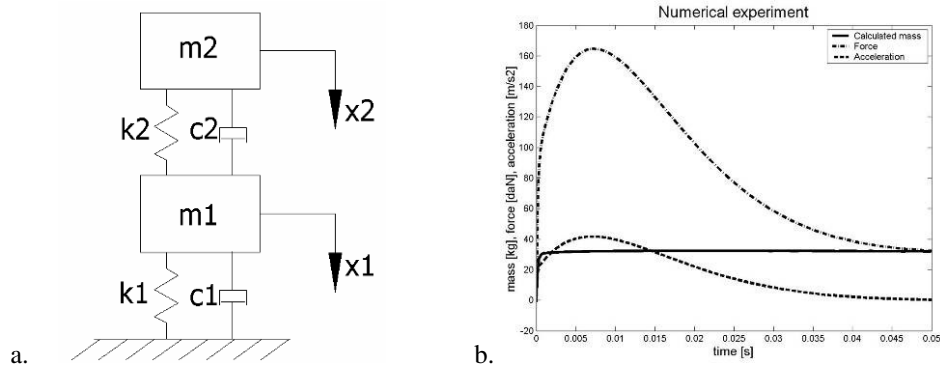


Figure 6. Numerical model; a. schema of the model, b. results obtained by used the model

Experimental verification - Drop test stand

The main parts of the drop test stand (see Fig. 7 b) were a magneto-rheological (MR) damper (1) mounted in a vertical position, a frame and a carriage. The stand was fixed to a foundation plate in order to reduce measurement noise. The lift mechanism enabled to conduct the drop tests up to 700 mm height. The mass (2) was guided by a rail system embedded in the frame, to ensure the stability of the vertical movement. The impact of the dropped carriage took place via a rubber bumper (3) located on the impact surface.

During the tests the following signals were acquired (Fig. 7b): a force signal from sensor fixed to a piston rod of the MR damper (4) in order to measure the full impact history, a signal from an optical switch (5) acting as a trigger and enabling determination of the horizontal speed of the carriage just before the impact. The test procedure covered also measuring of accelerations in two points: deceleration of the falling mass (6a) and acceleration (6b) of the piston rod of the MR damper (7).

Experimental mass identification

Impact forces acquired during the experiments with several masses had characters showed in Fig 8a. The critical maximal value of the force was recorded after 9 – 15 ms from the beginning of the phenomena dependently on the dropped mass.

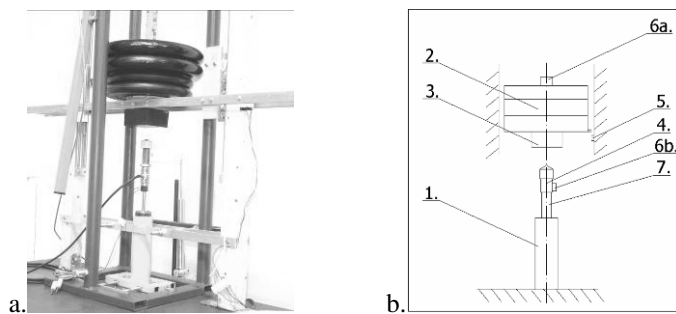


Figure 7. Drop test stand; a. general view, b. main parts and sensors distribution

The process of the mass identification was performed in two routines: on the basis of deceleration of the falling body and on the basis of acceleration of the impacted body (piston rod). Accelerations measured in the two locations were characterised by curves presented in Fig 8b. In order to obtain a meaningful signal from the acceleration of the piston rod it was conditioned with a low pass filter (see Fig 8b). Results of the mass identification on the basis of the falling body deceleration were performed for a series of masses. The meaningful mass values were observable after 2-4 ms from the impact instant (see Fig. 9a).

Mass identification on the basis of the impacted body acceleration was performed on the basis of the filtered signal. The results of the analysis and comparison between both methods are depicted in Fig. 9b.

Much better results of the mass identification were achieved for the case where the deceleration of the falling body was used. The data enabled to perform reliable dynamic mass identification at the beginning of the impact phenomena, much sooner than maximum force value was observed. On the contrary, when the acceleration of MR dumper piston was used the mass was much less reliably identified and the value was observable after 20 ms from the impact instant (see Fig. 9b). It was caused by the fact that the mass identification was possible only when the falling body and piston rod moved jointly.

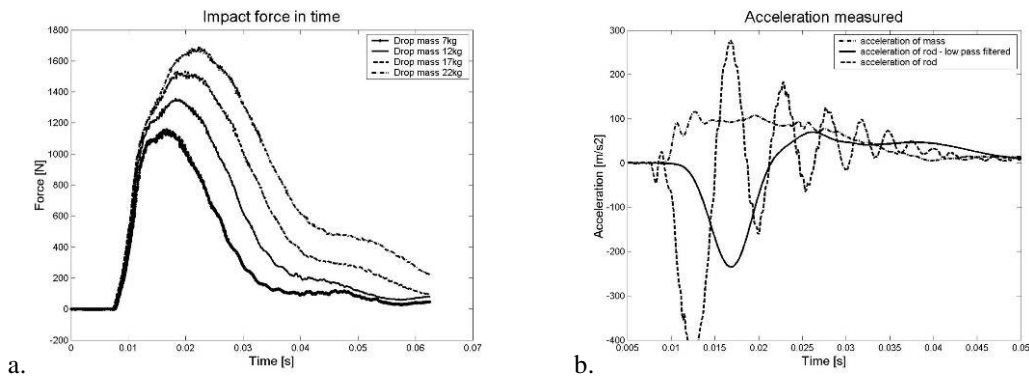


Figure 8. Measured signals for the drop test; a. force under the dissipater, b. acceleration measured on the falling mass and top of MR damper

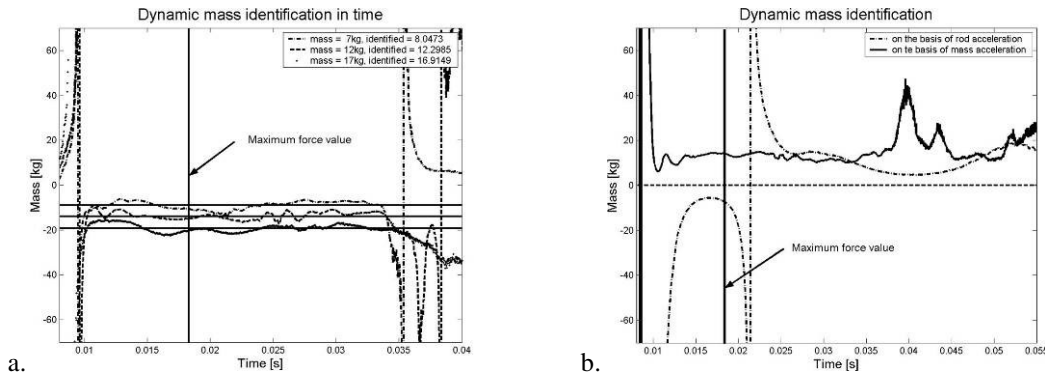


Figure 9. Mass identification; a. accelerated measured on the falling mass, b. accelerated measured on the top of MR damper

CONCLUSIONS

Using the piezoelectric sensor for load and mass identification is reasonable. In the case of dynamic excitation, they are very competitive due to short response times in comparison to the strain gages.

Real time mass estimation in case of the impact load excitation with applied two sensors (accelerometer and force) is feasible. However location of the accelerometer is very important. When the accelerometer is fixed to the falling body precise mass identification is feasible in a short time after the impact. When the accelerometer is placed on the impacted body the detection is far more difficult and feasible after longer period. Nevertheless it would be profitable from an applicability point of view to work out an algorithm that would allow a mass identification on the basis of the impacted body acceleration.

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REFERENCES

1. J. G. Webster, "The Measurements Instrumentation and Sensors Handbook", CRC Press LLC 1999, chapter 20.
2. C.M. Harris, C. E. Crede, "Shock and Vibration Handbook", McGraw-Hill Company 2002, chapter 15.
3. T. A. Polak, C. Pande, „Engineering Measurements Methods and Intrinsic Errors“, Professional Engineering Publishing 1999, chapter 4.
4. W. Schulz, J. Seim, E. Udd, M. Morrel, H. M. Laylor, G. McGill and R. Edgar, "Traffic monitoring/control and road condition monitoring using fiber optic based systems", available at http://www.bluerr.com/papers/BRR-1999_SPIE_Vol3671_p109.pdf.
5. G. Mikułowski, T. Varga, J. Holnicki-Szulc, "Real Time Impact Load identification", II Eccomas thematic conference on smart structures and materials, Lisbon 2005.
6. http://www.radwag.pl/english/index_en.htm.
7. A. Preumont, "Active vibration control", Structural Control and Health Monitoring Advanced Course – SMART'01, Warsaw 2001, pp. 13-53.
8. K. Sekuła, J. Holnicki-Szulc, "Built-in self-test for the system traffic load identification", Computer Methods in Mechanics, Częstochowa 2005.
9. G. Gautschi, "Piezoelectric Sensors", Springer-Verlag Berlin Heidelberg 2002.
10. K. Sekuła, J. Holnicki-Szulc and L. Knap, "New sensor for monitoring of traffic load", Structural health monitoring 2004, pp. 541-547.