ANNALS OF THE ORADEA UNIVERSITY
Fascicle of Management and Technological Engineering
ISSUE #1, MAY 2013, http://www.imtuoradea.ro/auo.fmte/

SOME REMARKS UPON USING SHOCK SENSORS IN DYNAMICAL SYSTEMS

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***Abstract*—**The paper presents some aspects concerning the function of the acceleration sensors from impacting systems. On an existing device, a new acceleration sensor was mounted instead of a shock sensor, from economy reasons, and then tests were performed. Using a ballistic pendulum, composed from a prismatic body with two steel balls attached to the ends, a planar motion was obtained by the suspending method. The prismatic body has attached the acceleration sensor, the sensor signal generated by the sensor and the characteristic signal for time period during which the active part of the pendulum collides different bodies are compared using a memory oscilloscope. From the experimental tests it was concluded and validated by literature that the acceleration values from impact phenomena are considerable greater than the working range of the acceleration sensor. Thus, the use of acceleration sensor in the study of impact phenomena is inappropriate because can lead to erroneous values and conclusions.

***Keywords*—**ballistic pendulum, dynamical systems, shock sensors.

I. INTRODUCTION

IN order to find the concordance between theoretical and experimental results for central collision between two balls, the author and co-workers used a ballistic pendulum [1], suggested by Goldsmith [2], Fig. 1.

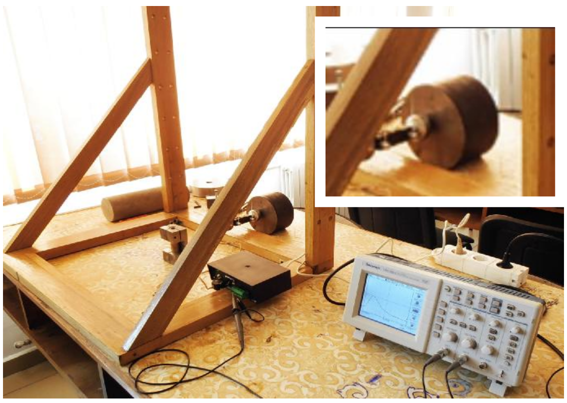

Fig. 1. Balistic pendulum.

The theoretical model proposed by Lankarani [3] and modified by Flores [4] and Machado [5] provides differential equation describing the time variation of the force in damping impact for a central collision between two metallic balls. Experiments were made using a ballistic pendulum with an acceleration sensor placed on its body, Fig. 2. to validate the above mentioned theoretical model. Electrical signal generated by the acceleration sensor is amplified and then analyzed by means of memory electronic oscilloscope.

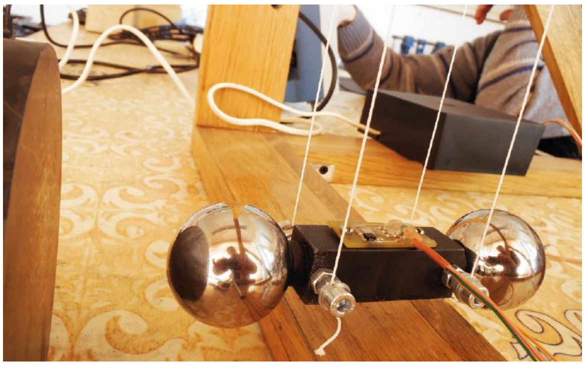

Fig. 2. Acceleration sensor mounted on pendulum.

The use of acceleration sensor instead of shock sensor limits the use of the device due to the low threshold of the sensor block $\cong 10g$, as opposed to the impact sensor, with a maximum of blocking having the order of magnitudes $10^4 g$ (where g is the gravitational acceleration) So, the launching amplitudes were strictly limited.

$$\psi_0 \le 5^{\circ} \tag{1}$$

Since the length of the pendulum is **0.7m** a simple calculation shows that the maximum impact speed that will ensure the above conditions is:

$$\mathbf{v_0 = \sqrt{2gL(1-\cos\psi_0)}} \tag{2}$$

The value of initial velocity corresponding to above equation is *0.2m/s.*
The vertical displacement corresponding to the above angular displacement is:

$$\Delta h = L(1 - \cos\psi_0) \qquad (3)$$

In our experiment the maximum value of vertical displacement is around *3mm.*

Johnson's observation [6], quoting Zukas et al. [7], should be emphasized here, who shows that in order to avoid plastic deformations is necessary to limit the maximum contact pressure to the value $1.6Y$, where Y is the yielding stress. After some calculations, Johnson gave an approximate relationship which allows finding the speed of occurrence of plastic deformations V_Y .

$$\frac{1}{2} m V_Y^2 \cong 53 R^3 Y^5 / E^{*4} \qquad (4)$$

where $m = m_1 m_2 / (m_1 + m_2)$ is reduced mass of the system and $R = R_1 R_2 / (R_1 + R_2)$ is the reduced radius of the contact.

When a homogeneous ball collides the flat surface of a relatively large body mass $m_2 \to \infty$, the above calculation simplifies to:

$$\rho V_Y^2 / Y = 26 (Y / E^*)^4 \qquad (5)$$

For the case of two colliding balls from hardened and tempered steel, with yielding stress $Y = 10^9\,Pa$, it is found that the initial velocity is $V_Y = 0.14 m/s$. If the ball is a free falling one, then $h_Y = V_Y^2 / g$. Performing calculations is obtained that $h_Y \cong 1mm$. Johnson points out that, practically, all collisions between metallic bodies are accompanied by plastic deformation.

II. THE EXPERIMENTAL DEVICE, RESULTS AND COMMENTS

In the present paper, the same rig described in [1] is used to which an electrical circuit was attached, consisting of copper connectors with terminals connected to an oscilloscope.

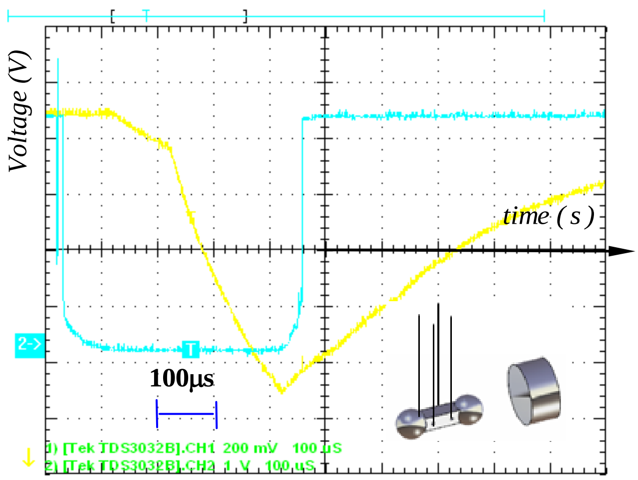

Fig. 3. Stainless steel ball – plane surface impact.

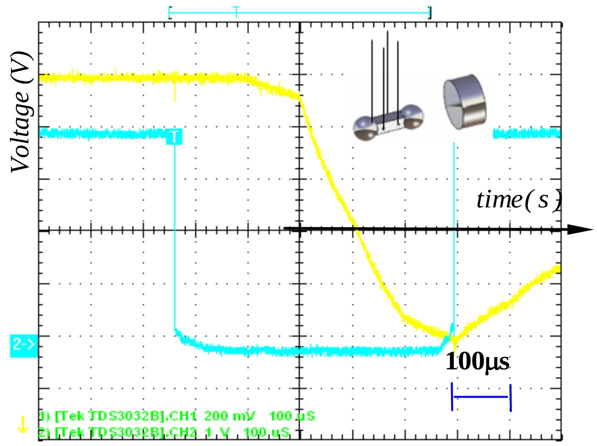

Fig. 4. Impact between a steel ball and plane bronze surface.

The circuit is closed during the period while the ball-shaped end of the pendulum is in contact with the other surface of the colliding body tested. Several tests of impacts between ballistic pendulum and front faces of the metal cylinders of hardened steel, aluminium and bronze respectively, were performed

In Fig. 3-5., there are presented the plots generated by the oscilloscope for the variations of the impact force and contact periods corresponding to cases. The time base is the same for all plots. The vertical axis corresponds to voltage registered in the two circuits (the sensor and the contacting ball-disk) but the experiments from the presents work consider only the time period, measured on horizontal axis.

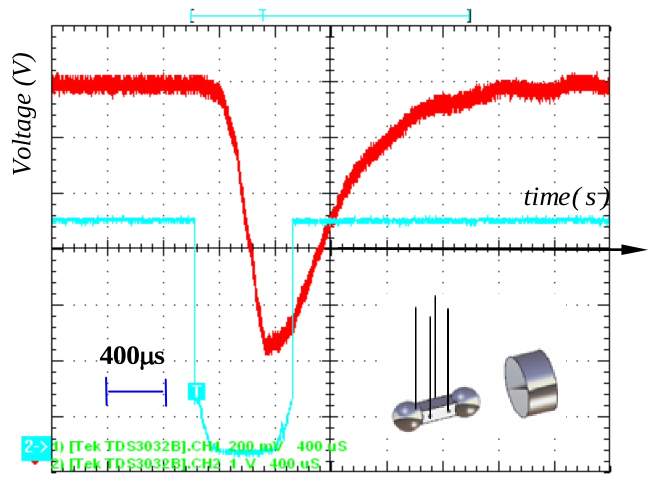

Fig. 5. Impact between a steel ball and plane aluminium surface.

From Figs. 3-5., it is observed that for the impact studies mentioned, a delay occurs between the closure moment of the electric current in the sensor and the occurrence of the signal generated by the acceleration sensor. In all three cases it was observed that the limit of the sensor was seriously exceeded. From Fig. 3., the time period of the impact can be assessed, $t_{collision} = 0.42ms$.

Flores' equation is used to estimate total contact times [4]:

$$\mathbf{F} = \mathbf{K}\,\mathbf{x}^{3/2}\left[1 + \frac{8(1-e)}{5e}\,\frac{\dot{x}}{v_0}\right]. \tag{6}$$

where e is coefficient of restitution (COR) after Newton, defined using normal components of relative velocity after and before collision, v_0 is initial relative velocity and K is an a coefficient that takes into account the elastic characteristics and the local geometry around the contact points:

$$\mathbf{K} = \frac{4}{3(\eta_1+\eta_2)}\left[\frac{R_1R_2}{R_1+R_2}\right]^{1/2} \tag{7}$$

with $\eta_{1,2} = (1-\nu_{1,2}^2)E_{1,2}$, $\nu_{1,2}$, $E_{1,2}$, Poisson's coefficients and Young's moduli of impacting bodies, respectively.

For an value of initial velocity $v_0 = 0.2m/s$, the author integrates (6) and finds that COR providing a value for time collision close to the experimental one is $COR = 0.4$. For the same impact the experimental value obtained [2], is about $\cong 0.7$, that is, a much higher value. For these values of initial speed $v_0 = 0.2m/s$ and restitution coefficient $COR = 0.4$, the plot of acceleration variation during contact is obtained, Fig. 6., and from the graph it is observed that the contact period is $t_{collision\_th} = 0.403s$.

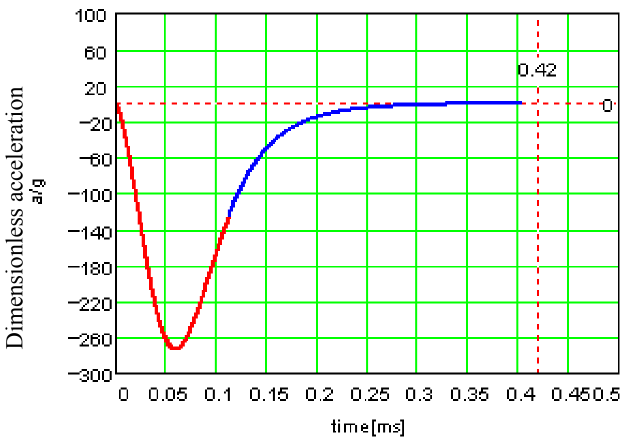

Fig. 6. Variation of acceleration during impact between a stainless steel ball and a metallic wall.

It should be noted the maximum acceleration value during the impact, $a_{max} \cong 270g$. The images in the above figures suggested the necessity of testing the correct working of the sensor in the accelerations domain for which it is designed. To this end, a coil spring was fixed to the body that would collide with the spherical end of the pendulum. The obtained plots of the force and contact time are shown in Fig. 7. It is noticed that the force signal period has practically the same value as the contact time.

Flores' model can not be applied in this case because the spring end geometry that collides with the spherical pendulum cannot be defined.

In order, to evaluate the maximum acceleration value we start from the assumption that the signal from the acceleration sensor has a sinusoidal shape, Fig. 7 and from initial imposed conditions $\mathbf{v(0) = v_0}$, the velocity variation results:

$$\mathbf{v(t) = v_0 \cos(2\pi t / T)} \tag{8}$$

where T is found from Fig.7. Consequently, $T/2 = 2 \cdot 4.8 \cdot 10ms = 0.096s$. The derivative of signal (8) lead to the acceleration formula:

$$\mathbf{a(t) = (-2\pi v_0 / T)\cos(2\pi t / T)} \tag{9}$$

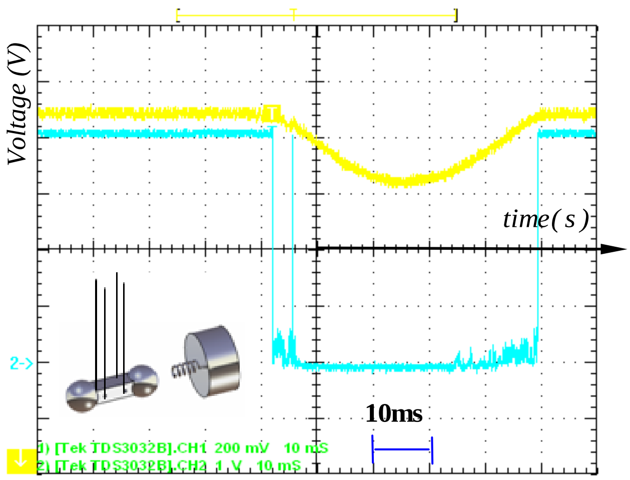

Fig. 7. Contact steel ball-spring-flat steel surface.

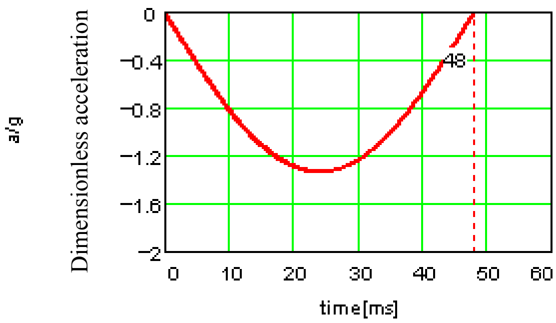

Fig. 8. Acceleration variation for impacting case shown in Fig. 7.

In this case the amplitude of acceleration is $\cong 1.3g$, value falling in the sensor's operation domain [8], [9].

Trying to extend the use of sensor, an intermediate small ball was interposed between the pendulum and spring, Fig. 9.

The trial failed, as can be seen from Fig. 10 and Fig. 11. Basically, the spring constant value has no influence, as the ball-ball contact has contact stiffness higher than the spring-ball contact.

Fig. 9. Ball coupled to a helical spring.

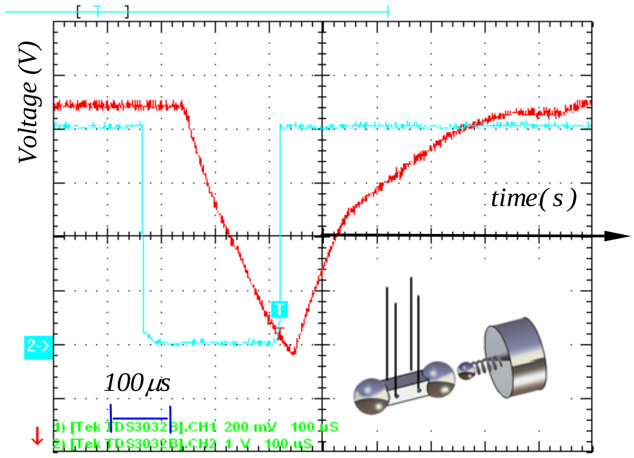

Fig. 10. Ball and soft spring between impacting bodies.

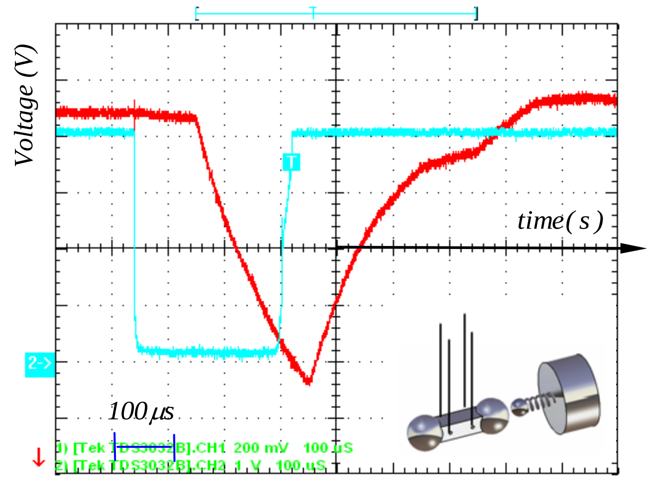

Fig. 11. Ball and stiffer spring between impacting bodies.

III. CONCLUSIONS

The paper presents an analysis of applying an acceleration sensor employed in a dynamic mechanical system subjected to shock. The main restriction consists in the upper limit value at which the sensor is blocked.

Using an extra electrical circuit designed to find the contact time between a fix body and a ballistic pendulum – on which an acceleration sensor is mounted, it is observed that, a delay occurs between the moments when the two signals start.

The system can be theoretically modelled as all the required parameters are known and it is noticed that the maximum acceleration is much higher than the prescribed limit blocking value of the sensor.

Adding an intermediate helical spring between the two colliding bodies, the two signals become synchronous. The experimental maximum acceleration value found for this case proves that the sensor runs in the designed operating domain. Supplementary trials with interposed ball-spring combinations between the impacting elements didn't demonstrate a correct running of the sensor.

The tests showed once again that for experimental research in shock phenomena, running limits of the acceleration sensors' must be first found by, even using theoretically rough models. Than, by the adequate sensors choose, one can rely on correct operating and feasible results.

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