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Determination of velocity and acceleration of the object in motion moving down along vertical cylindrical rails

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Abstract: *In this paper is presented the methodology for measuring the velocity and acceleration of the object in motion moving down along vertical cylindrical rails of laboratory device for pipe impact testing. For this purpose are used magnetic sensors and digital oscilloscope. An overview has been given of all relevant parameters, measurement procedure and measurement results. Since the measurement of velocity and acceleration was done indirectly, by measuring the time of movement of the object along a specified path, an overview has been given of all the necessary conversion formulas required to calculate the desired physical values.*

Keywords: *measurement; time; speed; acceleration; sensor*

1. INTRODUCTION

Measurement of velocity and acceleration at a relatively short distance usually is based on the measurement of displacement with respect to a reference point [1-3]. This paper describes laboratory exercise experimental determination of the speed and acceleration durng the free fall of the object. The method consists of measuring the time required for the object to overpass a certain path. To detect the position of the object electromagnetic sensors were used [4-7] whose operating principle is based on Hall-effect (*Hall efect*), fig. 1, placed in extreme positions at a distance equal to the length of path that the body should overpass.

Figure 1. *Hall effect electromagnetic sensor*

Sensors based on Hall-effect belong to the special electromagnetic sensors. Hall effect occurs when a semiconductor through which current flows is introduced into a magnetic field. If the semiconductor plate is in a fixed position perpendicular to the magnetic field of induction $\vec{B}$

and if through the plate flows current I (*fig. 2*), then on the holders of electricity effects principle of Lorentz force $\vec{F}$ perpendicular to the direction of current and induction:

$$\vec{F} = e\vec{v}_s \times \vec{B} \tag{1}$$

Where are:

$\vec{v}_s$ - mean velocity of charge carriers due to longitudinal electric field $\vec{E}$ that creates current I in the plate;

e - the amount of the charge, which is under the influence of a magnetic field.

Typical Hall-voltage value of the current is expressed in about few mV, and the value of the output resistance is from few ohms to several hundred ohms.

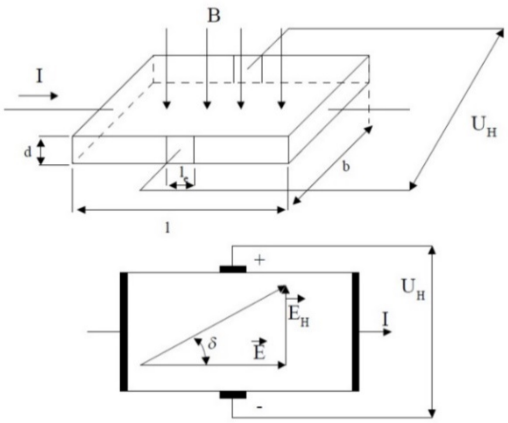

Figure 2. *Hall plate* [8]

Hall sensors are used to measure displacement affecting the change in the strength or direction of magnetic induction. Hall sensors are used to measure other quantities by the elastic elements which converted value into a proportional shift (force, preasure, acceleration, etc.). On figure 3 is shown use of Hall sensor for measurement and detection of displacement.

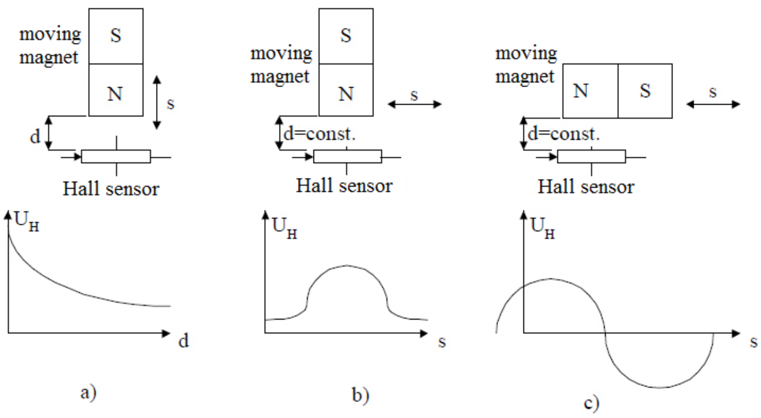

Figure 3. *Measurement of displacement by Hall sensors: a) magnet is moving perpendicular to the plate, b) i c) magnet is moving parallel to the plate* [8]

2. METHODOLOGY OF MEASUREMENT

In practical exercises of technical mechanics described in this paper, for measuring the velocity and acceleration during free fall, the laboratory device is used for testing pipes by impact (*fig. 4*). It is necessary to determine the velocity and acceleration of linear bearings when falling down along vertical cylindrical rails.

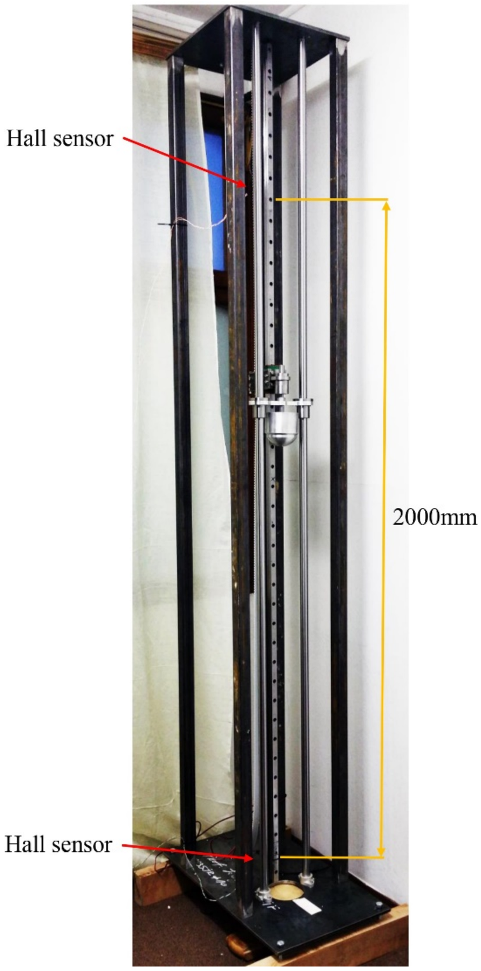

Figure 4. *Laboratory device for pipe impact testing*

The method consists of measuring the time taken for the object to exceed a predefined path - in this case the path of the 2 m. The sensor system consists of a permanent magnet attached to the moving object and fixed Hall sensor. Detecting the position of the object is done by using two electromagnetic sensors based on Hall-effect, set up in the end positions at a distance equal to the length of 2 m, ie. the lenght of the path that the object needs to overpass. The primary output parameter is the time of free falling object. Sensors detect the inflience of permanent magnets mounted on the object that is moving down along cylindrical rail. Time is measured by the digital oscilloscope (*fig. 5*).

Figure 5. *Digital oscilloscope*

The measurement is done when the object is lifted into the upper level position shown in figure 4 and released into free fall without initial velocity. The upper sensor registers the influence of permanent magnets mounted on the object. That signal on the oscilloscope is registred as an initial moment of movement of the object. In the moment of passing the object near the second mounted sensor in the lower end position, sensor receives the signal that the oscilloscope registers as a time at which the body took time equal to the distance between the two sensors - in our case the distance from 2 m. Then, on oscilloscope is shown the time divergence (t) between the two received signals, (*fig. 6*), which represents the time it takes the object to overpass the path of 2 m during free fall via cylindrical rails, with no initial velocity. All measurements were performed at a constant room temperature of 22 °C.

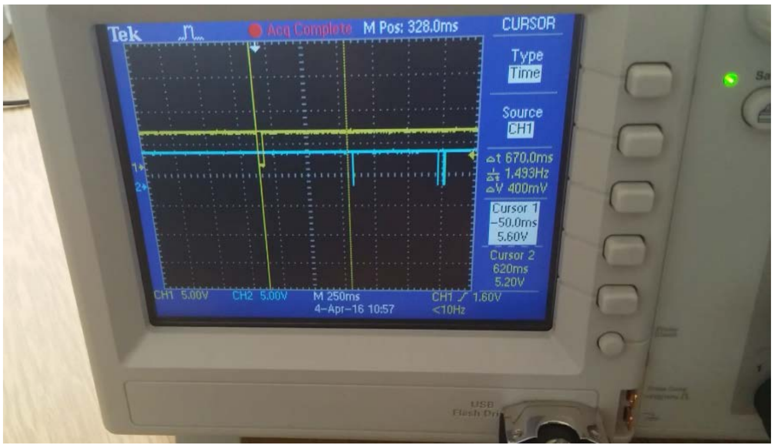

Figure 6. *Review of measurement on a digital oscilloscope*

3. RESULTS OF MEASUREMENTS AND DISCUSSION

Calculating the acceleration of the object

The acceleration of object during free fall without a initial velocity can be determined from the equation 2: [9-12]

$$a = \frac{2h}{t^2} \tag{2}$$

Where are:
h = 2 m – distance traveled during a free fall down along cylindrical rails;
t [ms] – measured time of free fall.
The measurement results and calculated values of acceleration of the object at a moment when it overpasses the path of h, are given in table 1.

Calculating the velocity of the object

At the initial moment, before relecing, at the height h, the object has the potential energy E_p, that transforms into the kinetic energy of E_k when the object starts free fall. Velocity of the object at a time when it overpasses the path of h, can be determined using the following expression:

$$E_p = E_k$$

$$mgh = \frac{mv^2}{2}$$

$$v = \sqrt{2gh} \tag{3}$$

Therefore, acceleration calculated on the basis of the measured time, using relations (2):

$$v = \sqrt{2ah} \tag{4}$$

The calculated velocity values for all measurements are given in the table 1.

Table 1. *Measurement results*

Measurements	Free fall time t $[ms]$	Acceleration a $\left[\frac{m}{s^2}\right]$	Velocity v $\left[\frac{m}{s}\right]$
1	650	9.4675	6.1538
2	650	9.4675	6.1538
3	640	9.7656	6.2500
4	660	9.1827	6.0606
5	640	9.7656	6.2500
6	650	9.4675	6.1538
7	640	9.7656	6.2500
8	640	9.7656	6.2500

Theoretical time during the free fall of the object can be calculated on the basis of the expression:

$$t = \sqrt{\frac{2h}{g}} \tag{5}$$

Given the fact that the gravitational acceleration in the central Serbia amounts $g = 9.804 \frac{m}{s^2}$, for height of h = 2 m, from expression (5) theoretical time during free fall of the object can be calculated and it values: t = 638.75 ms.

The theoretical velocity calculated using the expression (3) values: $v = 6.262 \frac{m}{s}$.

The analysis of the results and their comparing with the theoretical values, it can be concluded that the deviation is caused by the existence of friction between the bearing balls and beads, air resistance, etc. Consequently, the obtained values of time of movement of the object are greater, and the values of the acceleration and velocity of the object at the end of path are lower by a few percent compared to the theoretical value. In this case, the maximum difference between the values of the individual measurements are about 3%, due to minimum deviations of initial position of the object, from which the measurement starts.

4. CONCLUSION

The presented methodology can be used to precisely determine the velocity and acceleration of objects during free fall along cylindrical rods by described laboratory device, where time is measured of the moving object along a provided path. Also, based on the deviation of the measured values from reference (theoretical) values, time, velocity and acceleration, it can be determined the forces of friction between the bearing ball and cylindrical rods. Described exercise can be used in carrying out practical training in mechanics and physics, as well as other technical disciplines.

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