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VERYFICATION OF VELOCITY MESURMENT METHODS BY HIGH SPEED CAMERA AND ACCELEROMETER ON EXAMPLE OF IMPACT TESTER

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Abstract: *In the paper the velocity measurement accuracy analysis of impact testers dropping platen is shown. The measurement is carried out by two devices: accelerometer and high speed camera. During research it was assumed that dropping platen is moving in uniformly accelerated motion. The uncertainty of velocity measurement for each method was determined depending on the sampling frequency of measuring devices and the free fall height of dropping platen.*

Keywords: Linear velocity measurement, Uncertainty measurement, Impact tester.

1. Introduction

The key role in packaging construction are cushioning materials. The main tasks of this materials is absorption and dissipation of kinetic energy from sudden stop of object caused by collision. In order to predict the behavior of packages during collision the characteristic of cushioning materials (cushioning curve) (Young, 2009) is used. It is determined experimentally by means of so-called impact testers. In order to obtain reliable research results, the knowledge of linear velocity of dropping platen of the tester during collision with the sample is required.

Methods for the linear velocity determination are indirect methods. They use devices, which record the position or acceleration time history, then differentiate (position) or integrating (acceleration) (Webster et al., 2014).

Dropping platen position registration (marker placed on the platen, Fig. 1) is performed using a high speed camera (AOS Q-PRI). To read the position from a recorded video the method proposed in paper (Das et al., 2014) is used. Registration of acceleration is performed using the triaxle acceleration recorder (SAVER 3X90) attached to platen.

The purpose of this article is verification, which examined methods of velocity measurement is more accurate. Obtained research results allow to choose a more effective method to measure the velocity of the platen at the impact moment with the sample.

2. Object of research

The object of research is impact tester, which is used to test of the protective properties of cushioning materials. The device consists of dropping platen (3) with acceleration recorder (7), free falling from specified height on tested sample, placed on reaction mass (5). The free fall of the platen is initiated by disconnection of the electromagnet (6). The dropping platen is attached to guideway (4), on which it moves by a linear bearing (2). To the need of the presented paper all kinds of resistance omitted – it was assumed that dropping platen falls in accordance with gravity acceleration.

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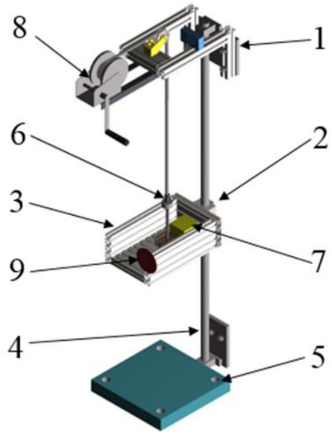

Fig. 1: Impact tester: 1 – crown, 2 – linear bearing, 3- dropping platen, 4 – guideway, 5 – reaction mass, 6 – electromagnet, 7 – triaxle acceleration recorder , 8 – rope winch, 9 – marker.

3. Uncertainty determination of velocity measurement

3.1. High speed camera

The method of the velocity determination from recorded video consists of two stages. The first stage involves marker extraction from recording. It is done by binarization of the extracted data stream from established color model. Through this process cluster of pixels is singled representing the marker, which we call BLOB (Binary Large Object) (Jia et al., 2008). In order to determine the position of BLOB centroid the individual pixels are considered as the squares of edge 1 pixel

$$Lp_i = \frac{\sum_{j=1}^{N} x_j p^2}{\sum_{j=1}^{N} p^2} \tag{1}$$

where x_j is the *j*-th pixel position in the rectangular coordinate system OXY of the frame, p is the length of the edge of the pixel ($p = 1$ px) and N is the number of detected pixels in BLOB which is determined by equation:

$$N = \frac{\pi}{4}\left(\frac{Lp_u \cdot d_B}{p_u}\right)^2 = \frac{\pi}{4}\left(w \cdot d_B\right)^2 \tag{2}$$

where p_u is the length of the square-shaped frame ($p_u = 0.957$ m), Lp_u is the number of pixels attributable to length p_u (value depends on the applied frame resolution), d_B is marker diameter ($d_B = 0.1$ m) and w is a constant calculated during p_u determination.

Uncertainty of object centroid position depends on the pixels number contained in the BLOB:

$$u(Lp_i) = \sqrt{\sum_{j=1}^{N}\left[\left(\frac{p^2}{N \cdot p^2}\right)^2 u(x_j)^2\right]} = \sqrt{N \frac{p^4}{N^2 p^4} u(x_j)^2} = \sqrt{\frac{u(x_j)^2}{N}} \tag{3}$$

where $u(x_j)$ is *j*-th pixel position uncertainty ($u(x_j) = 1$ px).

After the marker centroid position determination in each frame, the second stage is carried out: the platen displacement calculation:

$$\Delta s_i = w\left(Lp_i - Lp_{i-1}\right), \text{ when i=2,...,k} \tag{4}$$

where k is the number of captured frames.

Uncertainty of the displacement determination is calculated by following equation:

$$u(\Delta s_i) = \sqrt{2\left(w\right)^2 u(Lp_i)^2},\ \text{when i=2,...,k} \tag{5}$$

Knowing displacement *Δs*, we can determine the dropping platen velocity at the impact moment:

$$V_i = \frac{\Delta s_i}{\Delta t_u},\ \text{when i=2,...,k} \tag{6}$$

where Δt_u is set up sampling time.

Using the Eq. (4) and (6) and knowing that the uncertainty of sampling time $u(\Delta t_u)$ is so small that it can be neglected, the uncertainty of the velocity determination is defined by equation:

$$u(V_i) = \sqrt{\left(\frac{1}{\Delta t_u}\right)^2 u(\Delta s_i)^2},\ \text{when i=2,...,k} \tag{7}$$

Uncertainty of velocity is also caused by the error of numerical differentiation method. We can determine this value by Taylor series (Bjorck et al., 1987):

$$u(Vf_i) = \frac{1}{2} s_i^{(2)} \Delta t_u = \frac{s_{i-2} - 2s_{i-1} + s_i}{2\Delta t_u},\ \text{when i=3,...,k} \tag{8}$$

where s_i is a position of dropping platen in *i*-th frame.

Due to the two velocity uncertainties existence, the resultant value $u(Vres_i)$ is determined by equation:

$$u(Vres_i) = \sqrt{u(V_i)^2 + u(Vf_i)^2},\ \text{when i=3,...,k} \tag{9}$$

3.2. Acceleration recorder

The measuring velocity method which uses acceleration recorder relies on numerical integration by trapezoidal rule of the acceleration time history:

$$V_n = \sum_{i=2}^{m} \frac{a_i + a_{i-1}}{2} \Delta t_u = \frac{a_1 + a_m}{2} \Delta t_u + \sum_{i=2}^{m-1} a_i \Delta t_u \tag{10}$$

where V_m is the velocity determined at the m point, a_i is *i*-th measure of acceleration and Δt_u is set up sampling time.

The uncertainty of the velocity at the point *k* is determined, knowing that the uncertainty of sampling time $u(\Delta t_u)$ is so small that it can be neglected and the error of numerical integration method is presented by $\sum_{i=1}^{n} \frac{1}{12} a_i^{(2)} \left(\Delta t_u\right)^3$ (Bjorck et al., 1987):

$$u(V_k) = \sqrt{(k-2)\left(\Delta t_u\right)^2 \left(u(a)\right)^2 + 2\left(\frac{\Delta t_u}{2}\right)^2 \left(u(a)\right)^2 + \left(\sum_{i=2}^{m-1} \frac{a_i^{(2)} \left(\Delta t_u\right)^3}{12}\right)^2} \tag{11}$$

where $a_i^{(2)}$ is a second oreder derivative of acceleration (in uniformly accelerated motion $a_i^{(2)} = 0$) and $u(a)$ is uncertainty of the measured acceleration which is determined by equation:

$$u(a) = \frac{2a_r}{2^{(A/D-1)}} \tag{12}$$

where $a_r = 981$ m/s^2 is acceleration range and $A/D = 16$ bit is analogue/digital conversion.

4. Presentation and discussion of results

In order to evaluate the accuracy of methods to measure the impact velocity of dropping platen it was assumed that platen falls in accordance with acceleration of gravity. For this assumption the maximum uncertainty of velocity for each method was determined according to free fall height *h* and sampling frequency *f* (Fig. 2a). In the case of camera the relations between resolution and frame frequency was also taken into account (Fig. 2b). As can be seen, the acceleration recorder determines the velocity with lower uncertainty than camera for each height *h* and sampling frequency *f*. This is due to the fact that the camera resolution depends on the sampling frequency (Fig. 2b) affecting the BLOB uncertainty position and that the accuracy of numerical differentiation method depends strongly on the sampling time.

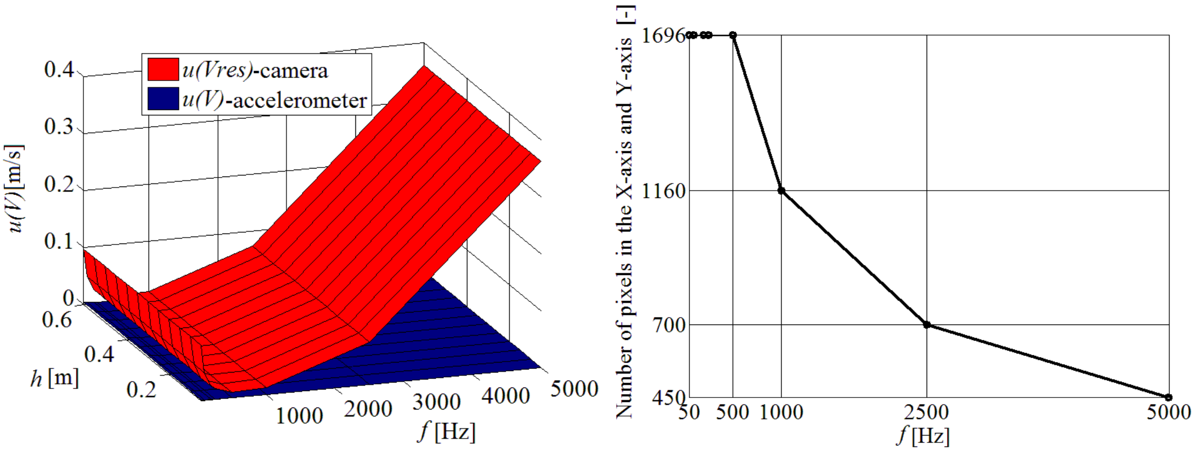

Fig. 2: a) Chart of linear velocity uncertainty as a function of free fall height and sampling frequency, b) chart of camera resolution in X-axis as a function of sampling frequency from which we acquired Lp_u value.

5. Conclusion

Uncertainty of measured dropping platen velocity was estimated for two motion registration methods (high speed camera and acceleration recorder) in a wide range of sampling frequency *f* and free fall height *h*. It turned out that in examined range of values *h* and *f*, the uncertainty of velocity determined by the acceleration recorder is lower than by the camera. This is due to fact, that intended use of acceleration recorder is to measure the kinematics parameters of one point, i.e.: displacement, velocity or acceleration. In case of deformation measure of flexible body (where the relative position of body points also change) the only way to measure such a complex motion is to use the multi-point measure method, which allows e.g. camera.

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