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IMPACT TESTING OF BIOLOGICAL MATERIAL ON THE EXAMPLE OF APPLE TISSUE

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Summary. The study presents the measuring position for determination of the dynamical behavior of vegetables and fruit. The main element of the device is an instrumented rigid physical pendulum made of carbon fiber. The pendulum arm was developed as a double arch connected with the external links. This construction enables attaining the desirable value of the quotient of the mass moment of inertia of the pendulum arm with a fruit and the arm without it as well as appropriate rigidity. The studies with the pendulum device application simulated the apple drop from a required height. The tests measuring pendulum rotation angle and fruit response force in time facilitated determination of the force – displacement correlation at impact event. The obtained displacement and impact force courses in time were presented graphically.

Key words: bruise of apples, measuring stand, pendulum.

INTRODUCTION

Losses of biological material caused by mechanical damage at harvest and post – harvest management constitute a severe problem for both, producers and industrial recipients. It is noteworthy that the losses include the quantitative decrease of fruit and vegetable weight as well as qualitative decrease of their trade value. That problem also concerns Polish producers of apples and processing plants that estimate their economic losses at hundreds of millions zlotys a year. Analyzing the mechanical damage of fruit and vegetable, Bollen [2006] found the following causes at fruit post – harvest handling: impact (at manual – mechanical harvest), compression (harvest – initial packing and storage), vibration (transport).

However, the highest damage rate results from loads of a dynamic nature, that is impact. Dynamic load is the one whose attachment causes propagation in material stress in the form of a wave. The velocity initiating this character of stress propagation depends on density and rigidity of the impacted material. As for fruit and vegetables, even low impact height (a few centimeters) can cause bruises of a dynamic nature, hence a necessity to determine their susceptibility to bruising. The literature provides numerous impact damage tests [Garcia – Ramos et al., 2004, Blahovec 2006, Van Linden et al., 2006, Van Zeebroeck et al., 2003, 2007]. The impact tests may by grouped according to Sitkey [1986]:

- impact of fruit or vegetable against the fixed rigid flat plane perpendicular to the motion direction,
- impact of biological material on the fixed rigid flat or profile plane inclined to the motion orientation at the appropriate angle,
- fruit or vegetable striking the other fixed fruits or vegetables without their mass center displacement,
- biological material striking the plastic plane.

Biological material force responses obtained at a free-fall test enabled to verify the mathematical model of viscoelastic body [Lichtensteiger et al., 1988] as well as determine the effect of a surface kind and drop height on the impact damage rate [Chen et al., 1991]. However, the results of the impact testing with application of a sphere of known dimensions and mass allowed to evaluate fruit firmness in the sorting lines [Chen et al., 1985, Delwiche et al., 1989].

Apple resistance to impact bruising was also established using the method single fruit impact against single fruit" [Pang et al., 1996] as well as impacting against the accessory rigid surface [Holt and Schoorl 1977]. The advantages of these methods are their fastness, simplicity and a non – destructive nature. However the tests have certain drawbacks, too. One of them is that a sample gets impacted lying down on the substrate so impact energy dissipates in more than one site which does not allow for its correlation with bruising rate. Besides, substantial variation of mass, dimensions and elasticity of fruits and vegetables observed within even a variety affects impact force value at free fall as well as the accuracy of the studied trait (e.g. firmness).

Therefore, many researchers focused on experiments with pendulum and resistance area use for simulating free fall and functional impact of biological material. The studies with the pendulum were carried out by two methods. The first consisted in attaching the biological material to the arm end and measuring the damage – related parameters at the impact moment on the flat plane of the force sensor. Bajema and Hyde [1998] suggested construction of pendulum formed from two pairs of suspending Kevlar lines combined with a wafer and spikes for specimen mounting. In the other method, the values of force, acceleration or displacement were obtained as a result of pendulum impacting piece with a force sensor onto the fixed area of fruit or vegetable [Van Canneyt et al., 2003, Van Zeebrock et al., 2003, Yen et al., 2003, Blahovec et al., 2004]. However, Bajema et al., [1998] developed the concept of combination of the anvil with the built – in force sensor and pendulum as a rotating hammer with the force and acceleration sensors. Both elements made the device to measure both, impulse loading and stress wave responses in the cylindrical shape samples of definite dimensions.

Taking into account the above information, it should be highlighted that studies on sensitivity to impact loading need to be conducted under conditions most similar to free fall at full control of force and sample displacement. The conditions can be satisfied by a special pendulum that guarantees stiffness of the specimen mounted to the arm and its minimum mass that does not affect significantly the impact force course. Thus, the major task is to minimize pendulum arm mass while retaining high rigidity that ensures measurement of momentary angular position associated with sample displacement at impact event. The procedures described in literature allow for the measurement of only force response in time function. The present study has proposed the construction of measuring position for sample reaction force in the displacement function at the investigated sample impact against flat plane.

MEASURING STAND CONSTRUCTION

The development of a measuring position followed the following design assumptions:

- technical feasibility of measurement head positioning along the vertical axis,
- regulation of measurement head position along the horizontal axis,
- providing a wide range of drop heights,
- measurement of pendulum angular position at definite accuracy,
- recording the impact force course,
- minimization of pendulum mass keeping appropriate rigidity of fruit attachment and its position stabilization at testing.

Besides, a possibility to mount acceleration sensors to both, the pendulum device and biological material studied. The measuring stand for impact testing, presented in Figure 1, is constructed from two rods mounted to the base and connected with three horizontal links. The rods were fitted with the measurement head with a piezoelectric force sensor Endevco model 2311 – 10 of 2,27 $mV \cdot N^{-1}$ sensitivity and measurement range ± 2200 N. The measuring head may be displaced in the vertical and horizontal plane and its position is set by adjusting screws. The pendulum arm is an operational element whose mass was minimized due to carbon fiber use. The arm construction ensures maintaining appropriate rigidity.

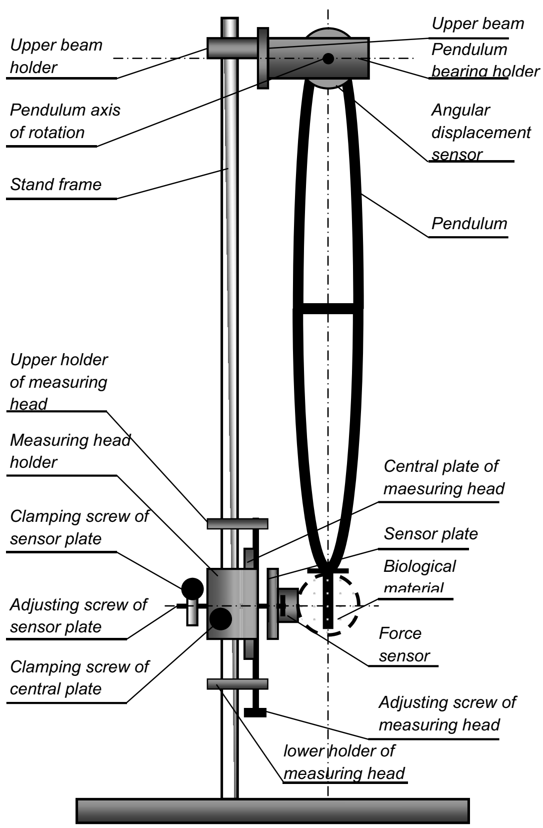

Fig. 1. Measuring stand to impact tests of biological materials

The pendulum is mounted on the axis of incremental optical encoder to record angular displacement Heidenhain model RON 275 at accuracy of 0,005^0. The sensor was linked to the converter card National Instruments model SCB – 68 that performs data acquisition from the sensor to be afterwards processed by LabView ver. 8.6.1. program. The data measurement of pendulum angular displacement in time was released directly from the LabView programming system while recording of impact force course was initiated by means of a laser – detector gate as presented in Fig. 2.

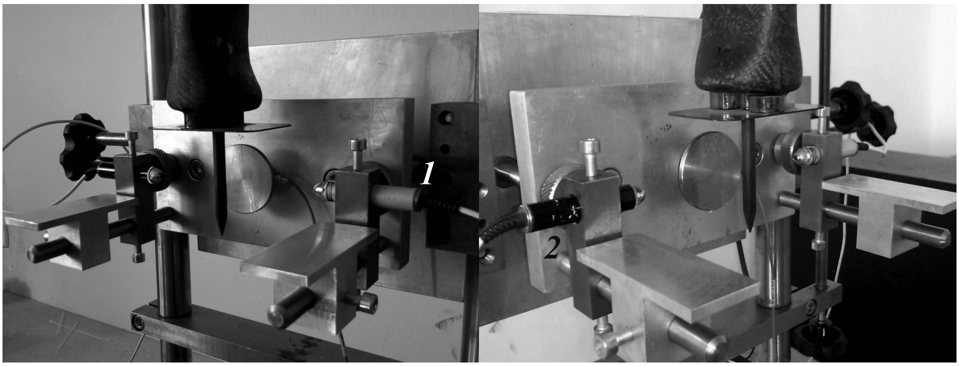

Fig 2. Release gate – laser (1), detector (2)

Construction of the pendulum arm is presented in Fig. 3. Two thin – walled tubes from carbon composite had their ends connected by links made of carbon laminate. They were filled with EPS – expanded polystyrene foam to ensure a suitable profile and shape of links. In the central part of the pendulum device, there was attached a connection stabilizer that at the same time stiffened the arm construction. The entire device was connected by liquid epoxy resin Epoxydharz L. In the pendulum top end, there was drilled a hole to mount the device at the axis of the angular displacement sensor, whereas the down end was equipped with a tang for research material mounting and its position stabilization. There was obtained uniform mass distribution of physical pendulum – 187g.

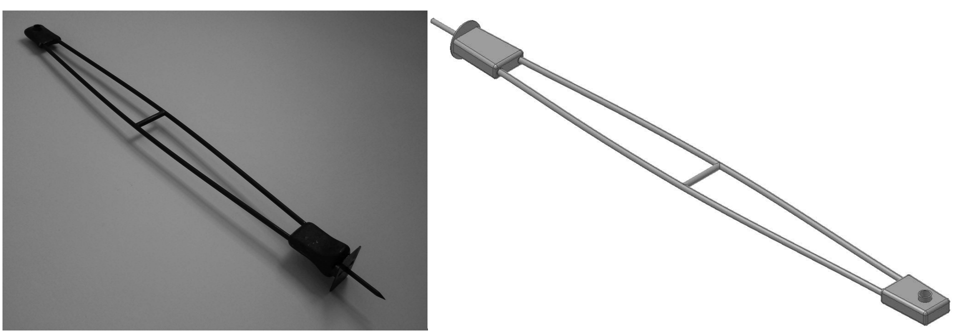

Fig 3. Pendulum arm

The mass moment of inertia of the arm with respect to the axis of rotation was 0,072592419 kg · m^2, while the mass moment of inertia of the pendulum with fruit (average weight 240g) reached 0,299417669 kg · m^2.

DESCRIPTION OF TEST COURSE

The testing included apples of *Jonagold* variety. During the measurement, the fruits fixed to the pendulum device struck the vertical rigid flat plane of the force sensor measuring element. There was made the initial evaluation of apple diameter along the axis running through the point of fruit contact with force sensor measuring plane and fruit mass.

Appropriate positioning of apple contact point with operational area of the force sensor was possible through adjusting screws for horizontal and vertical displacement of the main plate and measuring head. Besides, before the testing onset, the pendulum device was set in the vertical position, angular displacement sensor reset and the arm deflection corresponding to required fruit drop height established.

Apples aimed for testing were placed at the room temperature. For seven successive days, 10 apples were taken to undergo the test. It consisted in 5 – time impact of apple against operational area of the sensor at the pendulum arm deflection of 18,5 that corresponded to the free – fall from 50 mm height. To record impact force and pendulum angular displacement profiles, there was applied a designed and constructed measuring path and computer with the LabView programming system. There were obtained the courses of the aforementioned values in time as digital data and in graphical form.

TEST RESULTS

The impact tests performed provided the values of impact force and angular displacement, whose exemplary courses were presented in Figure 4.

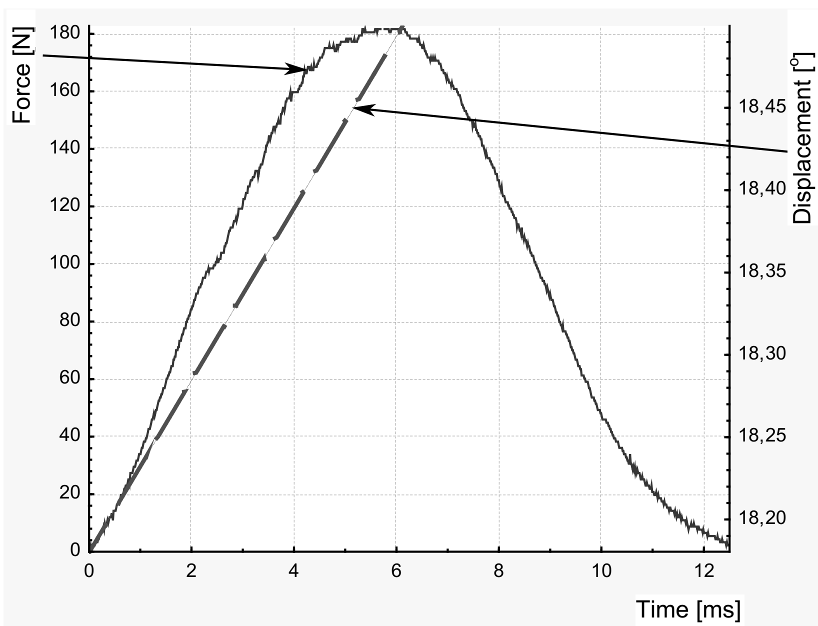

Fig 4. The values of impact force and angular displacement of the simple as independent time functions obtained in a single test

The measurement of impact force profile started at the moment of fruit contact with operational plane of force sensor (then $F_u = 0$). At this point, the angular displacement value recorded by the pendulum rotation sensor was $\delta = 0$ [°]. Then, impact force (F_u) reached the peak value. Owing to apple surface deformation, after some time the displacement rate obtained the value $\delta = \delta_{max}$ [°]. A recording mode of fruit displacement values during the impact moment was presented in Figure 5.

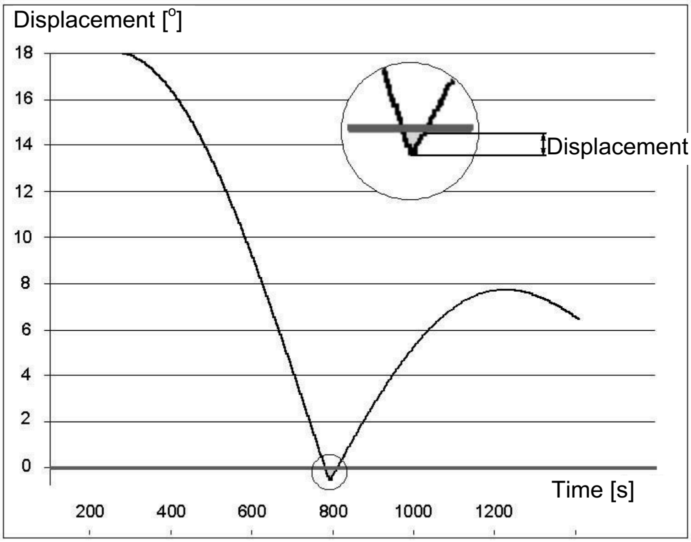

Fig. 5. Example of the angular displacement – time relationship for apple test during impact

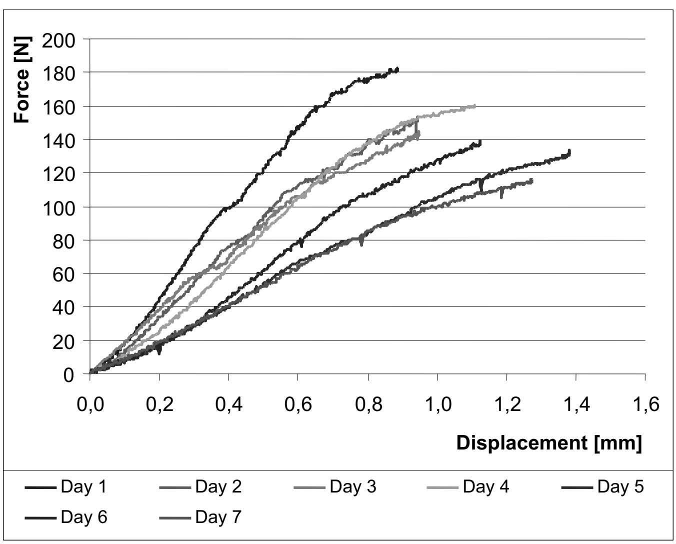

Fig. 6. Force – displacement relationship of the first impact for consecutive days of the test

Figure 6 illustrates the final measurement effect as response force – displacement relationship at the impact event. A detailed analysis of stress and deformation relationships will be possible to perform after including information about an apple shape in the contact area. Besides, it will be important to consider the regions in the contact area where the critical stress values were exceeded or not. Importantly, at this point it is possible to develop curves for different storage periods.

According to Figure 6 and 7, fresh fruits achieved higher values of reaction force at lower displacement rates and thus, the critical stress values were exceeded in them earlier. Stored apple deformation proved to be higher at lower maximum force values. Impact energy was higher in the case of fresh apples, which assuming similar critical stress values, implies the occurrence of greater areas of non – recoverable deformations.

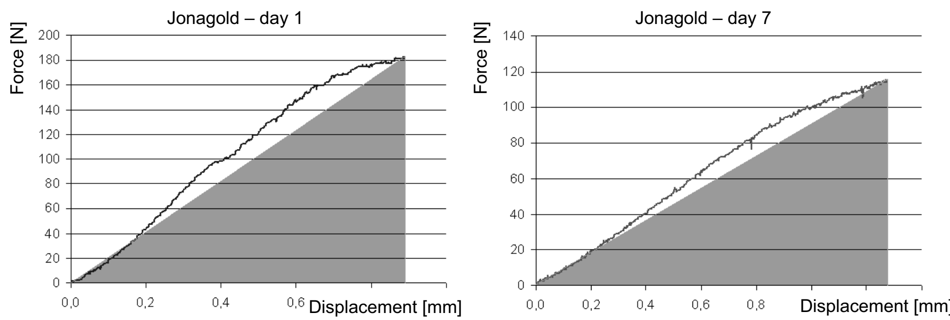

Fig. 7. Comparison of courses of force – displacement profiles for first and last day of testing

CONCLUSIONS

- A designed and developed measuring stand ensures full regulation of the measuring head so that initial vertical position of the pendulum device with maintained sensor-fruit contact could be possible.
- The physical pendulum construction in the form of a double arch tied with external links combined with carbon laminate use allowed mass reduction to 185g at working length of 1m and to ensure required rigidity of mounting as well as stabilization of the studied material during impact.
- The measuring device applied facilitates simultaneous recording of the courses of arm angular displacement and impact force at high accuracy.
- The obtained force reaction profiles during impact event allowed for a comparison of apple sensitivity to dynamic loads in different storage periods.

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TEST UDAROWY MATERIAŁU BIOLOGICZNEGO NA PRZYKŁADZIE TKANKI JABŁEK

Streszczenie. W pracy przedstawiono stanowisko do badań dynamicznych warzyw i owoców. Głównym elementem urządzenia jest sztywne wahadło fizyczne wykonane z włókien węglowych. Ramię wahadła zbudowano w postaci podwójnego łuku związanego zewnętrznymi łącznikami. Taka konstrukcja umożliwia uzyskanie korzystnej wartości ilorazu masowego momentu bezwładności ramienia wahadła wraz z owocem i ramienia bez owocu jak również odpowiednią sztywność. Badania z użyciem wahadła imitowały spadek jabłka z zadanej wysokości. Zastosowane testy pomiarowe kąta obrotu wahadła i siły reakcji owocu w czasie pozwoliły na wyznaczenie zależności siły w funkcji przemieszczenia podczas uderzenia Uzyskane przebiegi przemieszczenia i siły uderzenia w czasie przedstawiono w formie graficznej.

Słowa kluczowe: obicia jabłek, stanowisko pomiarowe, wahadło.