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Establishment of maize grain elasticity on the basis of impact load

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1. Introduction

In year 2004 maize was growing in the area of 145 million hectares, wheat in 217 million hectares and rice in 153 million hectares. But it was leading in yield (705 million tons) compared to rice and wheat. In 25 countries of European Unity maize for grain is grown in the area of 6.5 million hectares (gross output 53 million ton). Grain of maize can be usable for nutrition of peoples, forage of animals, manufacturing of textile, glue, starch, oil, beer, plastic, building materials and others.

When harvesting maize for grains a problem arises, how can harvesting be done with least grain damage. W. Baader [1] and others estimated that by harvesting of maize grain damage is much higher compared to other crops. The largest part of maize area in the world is harvested by combine harvesters with tangential threshing device and can be damaged up to 40% of grains with 35% moisture content. Settings of threshing devices and physical-mechanical properties of cobs and grains have an influence on the damage.

I. Petunina [2] established that properties of grains vary along the cobs but did not present comprehensive results of research. H. Waelti [3], I. Huszar [4], M. Kustermann [5] and others investigated grain elasticity (Young's modulus) on the basis of static method. R. Scherer [6], M. Kustermann [7] researched grain damage and elasticity on the basis of dynamical method. However by estimating the force for grain damage it was found out that loose grain by working tool were impacted or throw to the wall. Force is measured by quartz sensors with eigenfrequency of 200 KHz or by piezoelectric sensors.

Young's modulus is indirectly determined from measurement results and characteristics of grains. Cereals have different in statical and dynamical characteristics. To design efficient threshers for maize grains characteristics and especially elasticity of maize grains must be dynamically analyzed.

Many authors designated Young's modulus of maize grains and presented a variety of values from 50 MPa to 4000 MPa and noted that this module depends on grains moisture content. Investigators did not present the results for changing the grain Young's modulus along maize cobs.

Characteristics of grains and others materials can be researched on the basis of impact load. These methods have advantage over testing dynamical characteristics of different objects. V. Volkovas and others [8] applied this method for designating the characteristics of many-layer structures. R. Gulbinas and others [9] used similar method for the investigation of dynamics of optical tables.

The method for measuring of Young's modulus of grains on basis of impact load is introduced in article. Thus Young's modulus of grains can be researched also more parameters determined and chosen. These parameters can be used for the choice of optimal adjustment parameters and new design methods of threshing devices.

2. Methodology of experiments

Properties of maize grains of breed "G12" were determined in the Lithuanian university of agriculture, department of agricultural machinery and experimental analysis was performed at Kaunas university of technology, Institute of diagnostic of technology systems.

Two maize cobs with same diameter of cobs and different moisture content from 19.0% to 36.8% were sampled. From each cob five rows of grains were picked and their thickness was measured with vernier callipers. They were banked on the adhesive tape and numbered (Fig. 1). Moisture content of grains along the cob was established.

Fig. 1 Banked grains: *I*, *II* and *III* – rows of grains; *1-10* – grains in the rows

Active area of cross-section was designated within software computer-aided design „Autocad-2005" (Fig. 2). This area is equated to the most protuberant area of the grain that is checked with chalky paper underlying it under a strip of steel and impacting over the grain. The grains was scanned with high resolution (1200×1200 dpi), to the work field of computer program loaded, scaled with real size defined, profile of the area manually delineated („Draw/Polyline"), the area computed („Tools/Inquire/ Area") and according to the scale recalculated.

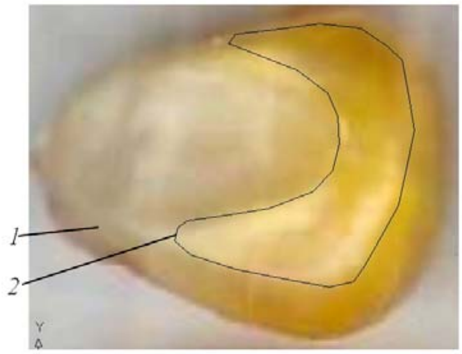

Fig. 2 Delineation contact area on grains: *1* – maize grain; *2* – delineated area of contact

But real area of contacts by hitting can differ from delineated area. For contacts area proofing was placed chalky paper between the grain and steel strip. After hit the area mentioned above was similar.

For the research „Brüel&Kjaer" measurement module „Pulse 3560" (instrument Nr.02336685, certificate of calibration Nr.0887022) connected to the impact hammer „Edevco 2302-10" with sensors of force and displacement was used [10].

According to the resonance frequency and decrement properties the strip of steel was choosen.

The strip of steel two millimeters in thickness was screwed to the ground so, that gap between the strip and the ground was three millimeters, distance from fixing point to the end of the strip was 180 mm, 15 mm whereof protruded from the edge of ground. Under the strip end the displacement sensor was placed. The grain was at the distance of 25 mm from the strip end and under it and 10 mm from the ground edge (Fig. 3).

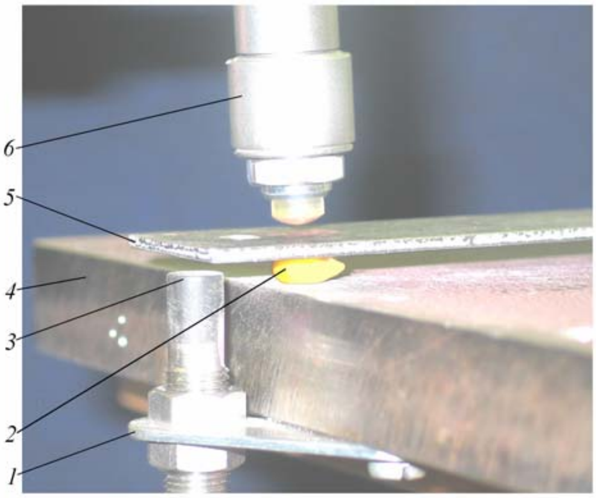

Fig. 3 Measurement scheme: *1* – holder for the displacement sensor; *2* – grain; *3* – displacement sensor; *4* – plate of ground; *5* – strip of steel; *6* – head of impact hammer

A hit with hammer was given over the strip of steel in the grain centre. Force and displacement in time were recorded and used for determination of parameters, which influence Young's modulus of maize grain. The Young's modulus of grain was defined by Hook's law

$$E = \frac{\sigma}{\varepsilon} = \frac{F l_1}{A \Delta l_1}, \text{ MPa} \tag{1}$$

where σ is stress, Pa; ε is relative elongation; F is force, N; A is contact area, m^2; Δl_1 is deformation, m; l_1 is grain thickness, m.

Most of the authors recommended in to Eq. (1) instead F and Δl_1 using the data derived by line from force F dependence curve on deformations Δl_1. Deformations curve was obtained from recorded experimental data of impact load and displacement, using investigation model presented in Fig. 4.

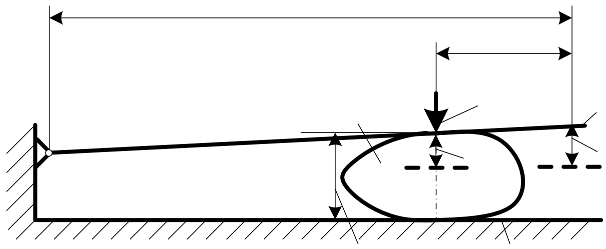

Fig. 4 Investigation model: *1* – ground; *2* – steel strip; K_1 is body characterizing properties of grain Young's modulus; F is force of impact load; l_1 is thickness of elastic body; l_2 is distance from maize centre to measurement point; Δl_3 is measured deformation; Δl_1 is real deformation; l_4 is length of steel strip

During experiment at the end of steel strip deformation Δl_3 was measured, but real deformation Δl_1 must be less because steel strip is fixed at one of the ends. Because distance l_2 =25 mm so Δl_1 must be recalculated

$$\Delta l_1 = \frac{(l_4 - l_2)}{l_4} \Delta l_3 = 0.861 \Delta l_3 \tag{2}$$

Experiment was performed with the grains along the cob also in hoop around the cob tested.

Analysis of measurement uncertainty. Total uncertainty U of direct measuring can be calculated [11-13]

$$U = \sqrt{U_{at}^2 + U_{sis}^2 + U_{ats}^2} \tag{3}$$

where U_{at} is random inaccuracy; U_{sis} is systematic inaccuracy; U_{ats} is random inaccuracy in the deduction.

Random inaccuracy is

$$U_{at} = \frac{t S_{dev}}{\sqrt{n}} \tag{4}$$

where t is critical value of Student's t-distribution; S_{dev} is standard deviation.

Systematic inaccuracy is

$$U_{sis} = \frac{t_{\infty,P}}{3} \frac{\delta_r x_{rib}}{100} = 0.00667 \delta_r x_{lim} \tag{5}$$

where δ_r is relative reduced error; x_{lim} is measurement scale boundary of the instruments, mm.

Extended uncertainty of indirect measuring according [11,12], is

$$U_{\Sigma}(y) = \alpha_{\Sigma}\sqrt{\sum_{i=1}^{n} W_i^2 U_i^2(x_i)} \tag{6}$$

where $W_i = \dfrac{\partial F}{\partial x_i}$ is absolute coefficient of influence of *i*-th parameters; U_i is uncertainty of *i*-th parameters (elements); α_{Σ} is coefficient of coverage of total uncertainty, accepted $\alpha_{\Sigma} = 2$.

Then Eq. (6) can be written

$$U_{\Sigma} = \alpha_{\Sigma}\sqrt{\sum_{i=1}^{n}\left[\frac{\partial F}{\partial x_i}\right]^2 U^2(x_i)} \tag{7}$$

Coefficients of coverage of total uncertainty are obtained according every partial derivative of each element. Finally uncertainty is calculated

$$U_{\Sigma}(y) = \alpha_{\Sigma}\sqrt{U_{gs}^2 + U_{kp}^2 + U_{je}^2 + U_{de}^2} \tag{8}$$

where U_{gs} is uncertainty of grain thickness; U_{kp} is uncertainty of contact area; U_{je} is uncertainty of dynamical force; U_{de} is uncertainty of deformation.

By Eq. (8) estimated total uncertainty of indirect measuring $U_{\Sigma}(y) = 3.25$ MPa.

3. Results of investigation

Established one grain mass of maize breed "G12" along the cob varies from 0.18 g to 0.27 g what is about 50%. Corn moisture content, its mass and size depends on the placement in the cob. The very heavy in weight (0.27 g) and density (1.10 g·cm^{-3}) one grain was in the 50-60 mm distance at the cob ground and the very light in weight at top of the cob. It is assigned the average mass (252.2±11.8 g) and density (1.09±0.008 g·cm^{-3}) of corn.

L. Špokas and others estimated that moisture content of grains depend on moisture content of pitch. Till now it was not advertised that moisture content of grain varies along the cob. Grain near the cob ground is more moistly because the cob nutritive exchanges through pitch.

Moisture content of grains varies on the cobs:

- in the 1st cob from 19.0% to 28.9%, average 25.6±0.8%;
- in the 2nd cob from 26.3% to 36.8%, average 33.1±0.9%.

According to the results of investigations the range of variations of grain moisture content along the cob is the higher the higher is average moisture content.

It is defined that grain Young's modulus differs on the separate cobs and vary along the cob (Fig. 5).

Grain Young's modulus was the highest in dryiest cob (U_{1avg}=25.6%) and the lowest (U_{1avg}=33.1%) in wettest cob. Estimated, that grain Young's modulus of maize varies with the grain moisture content (Fig. 6).

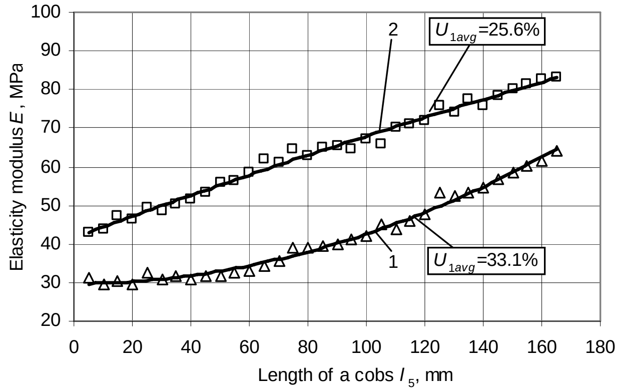

Fig. 5 Variation of Young's modulus E along the cobs length l_5: 1 and 2 – cobs with different average grain moisture content U_{1avg}

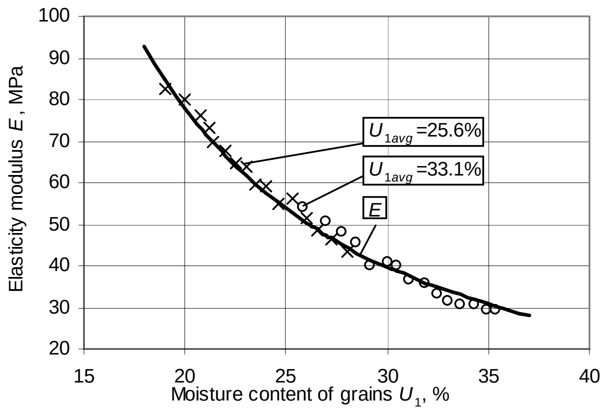

Fig. 6 Young's modulus E dependance on the grain moisture content U_1 in the 1 st and 2 nd cob: U_{1avg} – average moisture content of grains: $E = 11229 \cdot U_1^{-1.66}$

4. Conclusions

1. It was recommended the simple and effective method of Young's modulus identification of maize grains on the basis of impact load.
2. Grain Young's modulus varies along the cob and is the highest at the top of cobs where the moisture content of grains is the lowest.
3. Direct Young's modulus dependence of maize grain of moisture content was established and can go to very high values by sinking the moisture content.
4. The proposed method to establish Young's modulus of maize grains is new and opens wide possibilities for the analysis of physical-mechanical properties many of plants.

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KUKURŪZŲ GRŪDŲ TAMPRIO NUSTATYMAS IMPULSINĖS APKROVOS METODU

R e z i u m ė

Nuimant drėgnus (apie 35% drėgnio) kukurūzų grūdus, iki 40% jų gali būti sužalojama. Grūdų sužalojimas labiausiai priklauso nuo jų tamprio. Buvo nustatyta, kad grūdų drėgnis kinta išilgai šerdies, kartu kinta ir jų tampris. Tyrimai pagrįsta, kad grūdų tampris priklauso nuo jų drėgnio ir kinta nuo 35 MPa iki 85 MPa. Straipsnyje pateiktas metodas grūdų tampriui nustatyti impulsine apkrova. Naudojant šį metodą galima įvertinti realias kukurūzų burbuolių kūlimo sąlygas ir parinkti optimalius technologinius parametrus naujų kūlimo metodų kūrimui.

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ESTABLISHMENT OF MAIZE GRAIN ELASTICITY ON BASIS OF IMPACT LOAD

S u m m a r y

By harvesting of wet maize (moisture content of grains about 35%) up to 40% grains can be damaged. Grain damage mostly depends on their Young's modulus. It was established, that moisture content of grains varies by length of the cobs the grain Young's modulus varies as well. It was estimated, that Young's modulus of grains changed with moisture content of the grains and varied from 35 MPa to 85 MPa. The introduced in the article method of estimating grain Young's modulus on basis of impact load enables to regard real condition of threshing, to choose optimal technological parameters for generating new methods of threshing.

В. Волковас, С. Петкявичус, Л. Шпокас

ОПРЕДЕЛЕНИЕ УПРУГОСТИ КУКУРУЗНЫХ ЗЕРЕН МЕТОДОМ ИМПУЛЬСНОГО НАГРУЖЕНИЯ

Р е з ю м е

При уборке влажной (влажность зерен около 35%) кукурузы повреждается до 40% зерен. Повреждение зерен больше всего зависит от их упругости. Было установлено, что влажность зерен меняется по длине початка, тем самым меняется и упругость зерен. Исследовано, что упругость зерен зависит от влажности в пределах от 35 МПа до 85 МПа. В статье предложен метод определения упругости зерен, с помощью импульсного нагружения. Применение метода дает возможность учета реальных условий обмолота початков кукурузы, позволяет подобрать оптимальные технологические параметры при создании новых средств обмолота.

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