ACTA Acta Sci. Pol., Technica Agraria 9(3-4) 2010, 19-27

INVESTIGATION ON INERTIA CHARACTERISTICS OF CORNCOBS

Dmytro Kuzenko, Larysa Kuzenko, Zenovij Vantukh
Lviv National Agrarian University

Abstract. The theoretical and experimental characteristics of corncob inertia during its separation was presented. A corncob system presented through its design and movement parameters analysed together with the operating mode of machines for separating of cobs was considered. There were implemented three methods for theoretical simulation and analysis of the separating machine for corncobs application during the research. The formulas with suitable software program facilitating the cob inertia calculation were proposed.

Key words: the mechanism to separate corncobs, pulling speed, inertia moment of corncob

INTRODUCTION

Corn harvesting is an intensive process, which requires the expenditure of labour and energy in a restricted period of agrotechnical requirements. This technological process is also characterized by complicated technological operations, which it comprises and absence of linear connection which would link these technological practices. Therefore, search for new technical means for corn harvesting and modernization of separately working units of already existing harvesting aggregates is the current task in the modern agricultural production.

One of the basic working units of combine corn-harvesters, which is responsible for both, the whole harvesting process and the end-product quality, is a corncob-separating machine. The analysis of the scientific literature and technical reports showed that the main drawback of the present working machinery is use of one-way operation mechanical elements in the system "cob-stem", i.e. during the process of a stem pulling by rollers connection, there are defects resulting from force application – the force of disruption [Kuzenko and Vantukh 2009].

Owing to the research work performed to intensify this technological process, we propose using a separating machine with multiple-factor [Kuzenko and Pastushenko 2003,

Corresponding author – Adres do korespondencji: Dmytro Kuzenko, Faculty of Mechanics and Power Energy, Lviv National Agrarian University, Volodymir Velekyj 1 Str., tow. Dublyany, Zhovkivskiy district, Lviv region 80381, Tel. mob. +38 0953915082

Karpusha 1970, Kuzenko 2002, 2007] operations for the system "cob-stem" (torsion, cutting, bending etc.), in particular for vibration.

Taking it into account as well as the fact that a corncob is a complicated system with different inertia characteristics of its elements (corncob spathe and stem), and consequently, with different parameters of its frequency and amplitude of vibrations; special attention should be paid to determination of inertia characteristics of the system, as a basis for the further theoretical simulation and practical application of principle construction of corncob-separating machine [Karpusha 1970]. Dimensional and weighing characteristics, destruction force and damages of elements of plants were studied.

Inertia characteristics of corncobs were studied by P.P. Karpusha [1970] to determine speed limit of stems pulling. In particular, the author proposed an equation for determination of corncob inertia moment.

$$I_M = \int_0^I \frac{F \cdot \rho}{g} \cdot \left(3 \cdot \frac{z}{I} - 3 \cdot \frac{z^2}{I^2} + 3 \frac{z^3}{I^3} \right) \cdot (z + r)^2 dz \tag{1}$$

where: z – cut height,
r – radius of foot rounding,
ρ – specific gravity of a corncob,
F_0 – cut area at foot means.

In this expression, the equation which describes corncob surface generant is introduce. But, taking into account considerable heterogeneity of forms of various corncob varieties especially their hybrids, this equation determines an individual case only.

Inertia characteristics of corncobs were not explored by other authors.

Regarding the importance of the problem, and taking into account that a number of new varieties and hybrids of corn have been bred recently, the purpose of this work is to develop methods and procedures for inertia characteristics of corncobs applying modern computer technologies.

MATERIAL AND METHODS

To achieve the aim, research results of experimental studies and methods of analytical calculations were used to facilitate comparative estimation of the outcomes.

The research included the corn variety "Odessa-210", the main size and weight parameters are summarized in table 1. Repeatability of measurements amounted to 100.
At the initial stage of analytical calculations to get rough determination of inertia characteristics of corncobs (complicated bodies that have one symmetry axis and a very wide range of form variations) the method of approximation was employed [Kuzenko and Vantukh 2009]. Thus, the components to which a corncob (complicated body of rotation) is divided, depend on the configuration and the required accuracy is approximated by geometrical simply-shaped bodies as follows:

– cylinder elements of identical height, taken with a larger radius;
– cylinder elements of identical height, taken with a middle radius;
– truncated cones and finite cone of identical height.

Table 1. Data obtained at research
Tabela 1. Dane uzyskane w badaniach

Number	d_e mm	h_n cm	$n_к$	l_n mm	α	$l_к$ mm	Corncob diameter every 3 cm Średnica kolby co 3 cm									M g	m_l g	$l_ц$ m
							d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9			
1	20	45	2	90	40	190	36	44	45	44	43	40	39			280	240	95
2	19	88	1	35	145	240	48	52	51	50	50	47	41			455	410	105
3	28	63	1	135	20	270	45	56	53	52	49	48	46	43	30	585	450	120
4	24	90	1	67	25	250	43	52	51	50	47	46	45	23		410	360	100
i	d_{ei}	h_{ni}	$n_{кi}$	l_{ni}	α_i	$l_{кi}$	d_{1i}	d_{2i}	d_{3i}	d_{4i}	d_{5i}	d_{6i}	d_{7i}	d_{8i}	d_{9i}	M_i	m_{li}	$l_{цi}$

d_e – stem diameter; α – corncob inclination; h_n – a height of corncob fixing; $l_к$ – corncob length; $n_к$ – corncobs amount; l_n – peduncle length; $l_ц$ – corncob centre of gravity; M – corncob weight; m_l – peeled corncob weight; d_1, d_2, d_3, … – corncob diameters.
d_e – średnica trzonu; α – odchylenie kolby; h_n – wysokość umocowania kolby; $l_к$ – długość kolby; $n_к$ – liczba kolb; l_n – długość szypułki; $l_ц$ – środek ciężkości kolby; M – masa kolby; m_l – masa kolby obranej; d_1, d_2, d_3, … – średnice kolb.

By the first method of approximation, when a corncob is divided into planes that are perpendicular to the symmetry axis, into simple geometrical bodies of rotation with the identical height h_i. Each element we present as a solid cylinder (fig. 1a), has the radius R_i equal to the radius of the larger basis of element. In this case we get a bit overrated results, but comparing experimentally obtained data to the analytical calculations – the rejection is less than 4.0%, i.e. this method can be accepted for determination of inertia characteristics of corncobs.

To get more accurate results, it is advisable to use the 3d method of approximation, by which a corncob is approximated by the truncated cones (fig. 1b).

RESULTS AND DISCUSSION

On the basis of "Microsoft Excel" software used to determine main inertia characteristics of corncobs ,there were established volumes of i-section (cylinder) and the whole corncob (V_i, V); a centre of gravity of i-section in relation to the fixing point (A) of a corncob (x_{0i}); static moments of i-section and the whole body in relation to the plane of YAZ (S_{xi}, S_x); moments of inertia of i-element by the body volume in relation to the major central planes Z_0OX_0 and X_0OY_0 ($I^V_{(Z_0OX_0)_i}$, $I^V_{(X_0OY_0)_i}$). The results of calculations by the method of cylinders-1 are given in the table 2. Then, the moment of volume inertia in relation to major central planes Z_0OX_0 and X_0OY_0 is defined as:

$$I^V_{Z_0OX_0} = I^V_{X_0OY_0} = \sum_{i=1}^{n} I^V_{(Z_0OX_0)_i} = \sum_{i=1}^{n} I^V_{(X_0OY_0)_i} = \sum_{i=1}^{n} \frac{1}{4} \cdot R_i^2 \cdot V_i \ . \quad (2)$$

a) b)

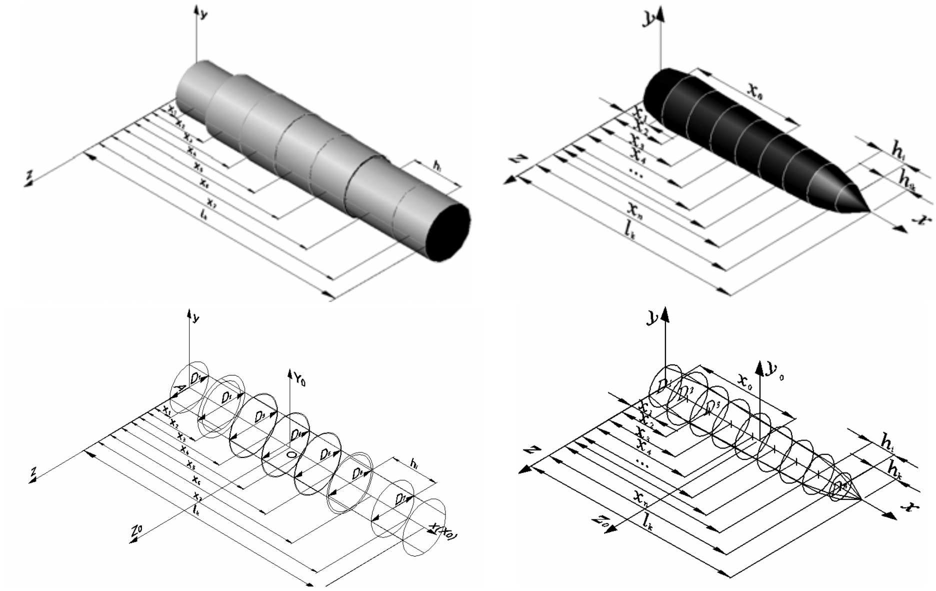

Fig. 1. Approximation of cob by elementary simply-shaped geometrical bodies: a – cylinder; b – cone
Rys. 1. Aproksymacja kształtu kolb poprzez proste bryły geometryczne: a – cylinder; b – stożek

We determine the coordinate of the body centre of gravity x_0 as a result of division of static moment of the body by its volume:

$$x_0 = \frac{S_x}{V} = \frac{\sum_{i=1}^{n} V_i \cdot x_{Oi}}{\sum_{i=1}^{n} V_i} \tag{3}$$

From the derived tabular output data and taking into account that a corncob is divided into cylinders of identical height h (except for the last cylinder, where oscillation of height from 0 to h is possible), we calculate expected moments of inertia of corncob volume in relation to main central axes and their crosspoint.

1. Relative to X_0X_0 (taking into account, that the axis X_0X_0 is simultaneously a symmetry axis):

$$I^V_{X_0X_0} = \sum_{i=1}^{n}\left\{I^V_{(Z_0OX_0)_i} + I^V_{(X_0OY_0)_i}\right\} = 2\sum_{i=1}^{n} I^V_{(Z_0OX_0)_i} = \frac{1}{2}\cdot\sum_{i=1}^{n}\cdot R_i^2 \cdot V_i \quad (4)$$

2. Relative to Y_0Y_0 (besides $I^V_{Y_0Y_0} = I^V_{Z_0Z_0}$):

$$I^V_{Y_0Y_0} = I^V_{Z_0Z_0} = \frac{1}{12}\cdot\sum_{i=1}^{n} V_i \cdot h_i + \sum_{i=1}^{n}\left[V_i \cdot x_{0_i}^2 + I^V_{(Z_0OX_0)_i}\right] - V \cdot x_0^2 . \quad (5)$$

We get:

$$I^V_{Y_0Y_0} = I^V_{Z_0Z_0} = \frac{1}{12}\cdot\sum_{i=1}^{n} V_i \cdot h_i + \sum_{i=1}^{n}\left[V_i \cdot x_{0_i}^2 + \frac{1}{4}\cdot R_i^2 \cdot V_i\right] - V \cdot \frac{\sum_{i=1}^{n} V_i \cdot x_{Oi}}{\sum_{i=1}^{n} V_i} \quad (6)$$

3. Relative to the point *A* (centre-of-mass):

$$I^V_A = \frac{1}{2}\left(I^V_{X_0X_0} + I^V_{Y_0Y_0} + I^V_{Z_0Z_0}\right). \quad (7)$$

Putting expressions (4) in equation (7), (6) and solving mathematical transformations we get:

$$I^V_A = \frac{1}{12}\cdot\sum_{i=1}^{n} V_i \cdot h_i + \sum_{i=1}^{n}\left[V_i \cdot x_{0_i}^2 + \frac{1}{2}\cdot R_i^2 \cdot V_i\right] - V \cdot \frac{\sum_{i=1}^{n} V_i \cdot x_{Oi}}{\sum_{i=1}^{n} V_i} . \quad (8)$$

Table 2. Calculation results by the method of cylinders-1 (MAX radiuses)
Tabela 2. Wyniki obliczeń przy użyciu metody walców-1 (promienie MAX)

Number of elem.	D_i	R_i	h_i	V_i	x_{0i}	S_{xi}	$V_i \cdot x_{0i}^2$	$I^V_{(Z_0OX_0)_i}$
	mm		cm	cm^3	mm	cm^4	cm^5	
Experimental method Metoda eksperymentalna				$\pi \cdot 2^2 \cdot 3$		4·5	5·6	$0.25 \cdot 2^2 \cdot 4$
1	36	1.8	3	30.52	1.5	45.78	68.67	24.7218
2	44	2.2	3	45.59	4.5	205.2	923.3	55.1673
3	45	2.25	3	47.69	7.5	357.7	2682	60.3561
4	44	2.2	3	45.59	10.5	478.7	5027	55.1673
5	43	2.15	3	43.54	13.5	587.8	7936	50.3205
6	40	2	3	37.68	16.5	621.7	10258	37.68
7	39	1.95	1	11.94	18.5	220.9	4086	11.3503
8	39	1.95	0	0	0	0	0	0
Sum – Suma (Σ)				262.56		2518	30982	294.763

Thus, the derived data in the expressions (4), (6) and (8) determine enough inertia characteristics of corncobs. With the derived equations, it is possible to define the moments of inertia in relation to any point, using the standard formulas of parallel transfer and turn on the certain angle of moments of inertia.

By the second method of approximation, when the cylinder elements of identical height h are taken by the middle radius of R_{mid}, which is evened

$$R_{mid} = \frac{R_i + R_{i+1}}{2} \tag{9}$$

The method of calculation is identical. Derived results are given in the table 3.

Table 3. Results of calculations by the method of cylinders-2 (middle radiuses)
Tabela 3. Wyniki obliczeń przy użyciu metody walców-2 (promienie średnie)

Number of elem.	D_i	R_i	h_i	V_i	x_{0i}	S_{xi}	$V_i{\cdot}x_{0i}^2$	$I^V_{(Z_0OX_0)_i}$
	mm	cm		cm^3	mm	cm^4	cm^5	
Experimental method Metoda eksperymentalna				$\pi{\cdot}2^2{\cdot}3$		4·5	5·6	$0.25{\cdot}2^2{\cdot}4$
1	36	1.8	3	30.52	1.5	45.78	68.67	24.7218
2	44	2.2	3	45.59	4.5	205.2	923.3	55.1673
3	45	2.23	3	46.12	7.4	358.4	2678	59.84
4	44	2.18	3	44.89	9.8	477.8	5021	54.86
5	43	2.14	3	43.54	10.5	578.2	7928	49.92

The third method of approximation (truncated cones) differs a bit from previous ones – first of all it is the use of other form as an elementary body (fig. 1, b). Basic architecture of construction of the computer program for data processing is analogical. The derived results are presented in table 4.

Table 4. Results of calculations by the method of truncated cones
Tabela 4. Wyniki obliczeń przy użyciu metody ściętych stożków

Number of elem.	D_i	R_i	h_i	V_i	x_{0i}	S_{xi}	$V_i{\cdot}x_{0i}^2$	$I^V_{(Z_0OX_0)_i}$
	mm	cm		cm^3	mm	cm^4	cm^5	
Experimental method Metoda eksperymentalna				$\pi{\cdot}2^2{\cdot}3$		4·5	5·6	$0.25{\cdot}2^2{\cdot}4$
1	36	1.8	3	37.81	1.6	60.48	96.74	30.62
2	44	2.2	3	46.64	4.511	210.4	949.1	56.43
3	45	2.25	3	46.69	7.489	349.3	2615	59.02
4	44	2.2	3	44.56	10.49	467.4	4902	53.92
5	43	2.15	3	40.58	13.46	546.3	7356	46.89
6	40	2	3	36.75	16.49	605.8	9989	36.75
7	39	1.95	1	11.94	18.5	220.9	4086	11.35
8	39	1.95	0	0	0	0	0	0
Sum – Suma (Σ)				264.91		2461	29995	295

For comparison of the derived results we shall make the comparative table of the basic indices of all three theoretical methods, and also partly experimental method (determination of centre of gravity). Comparative estimation is made by the following indices: the volume (V), centre of gravity (x_0) and the main inertia moments ($I^V_{Y_0Y_0}$ i $I^V_{X_0X_0}$).

Table 5. Results and relative errors from different methods of calculation
Tabela 5. Wyniki oraz błędy względne obliczeń przeprowadzonych różnymi metodami

Number of calc.	Volume Objętość		Centre of gravity Środek ciężkości		Moments of inertia Momenty bezwładności			
	V	ΔV, %	x_0	Δx_0, %	I_{xx}	ΔI_{xx}, %	I_{yy}	ΔI_{yy}, %
experim.	263.9		9.4					
(1)	262.56	-0.5	9.589	2.015	589.5		7329	
(2)	264.75	0.332	9.287	-1.2	593.3	0.643	7708	5.171
(3)	264.91	0.389	9.289	-1.19	590	0.076	7633	4.146

As we can see from the data (tab. 5) the relative errors in the calculation are lower than 5%, the most approximate are the data, derived by approximating truncated cone.

In order to determine inertia characteristics of a spathe, we employ the third method of approximation, by which a corncob is divided by planes, that are perpendicular to the symmetry axis, into simple geometrical bodies of rotation with the identical height h_i. Each element we present as a hollow truncated cone (fig. 2).

a) b)

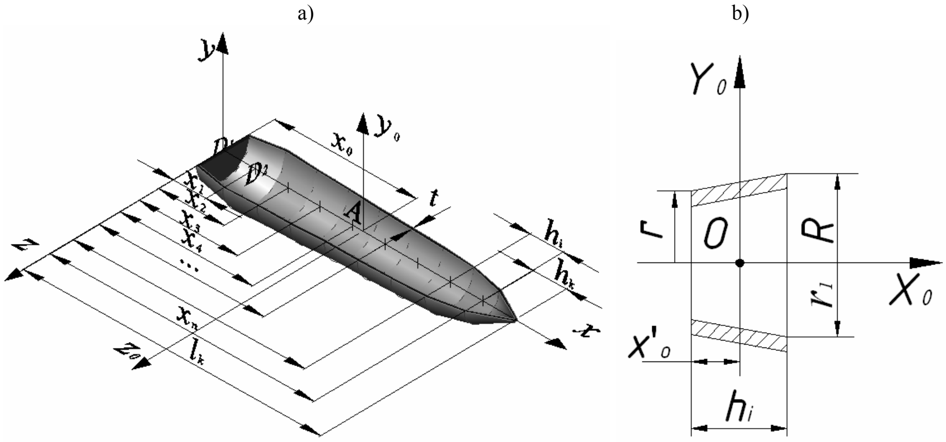

Fig. 2. Approximation of a corncob spathe by: a – the truncated cones, b – transversal cut of elementary section of the spathe
Rys. 2. Aproksymacja kształtu pochwy liściowej kolb kukurydzy: a – stożkami ściętymi, b – poprzecznym przekrojem podstawowej warstwy pochwy liściowej

Using the same method investigating inertia characteristics, as for corncobs, we calculate the moments of inertia of the spathe volume in relation to main central axes and their crosspoint.

1. Moments of inertia in relation to the main central planes of element (additional values):

$$I^V_{(Y_0OZ_0)} = V \cdot \left[\frac{1}{6} \cdot h^2 \cdot \left(3 - \frac{r + r_1}{R + r_1} \right) - x_0^2 \right], \tag{10}$$

$$I^V_{(Z_0OX_0)} = I^V_{(X_0OY_0)} = \frac{1}{20} \cdot V \cdot \frac{\left(R^5 - r^5 + r_1^5\right) - \left(R - r + r_1\right)^5}{\left(r - r_1\right) \cdot \left(R + r_1\right) \cdot \left(R - r\right)}. \tag{11}$$

2. Moments of inertia in relation to X_0X_0 (taking into account, that the axis X_0X_0 is at the same time the symmetry axis):

$$I^V_{X_0X_0} = 2\sum_{i=1}^{n} I^V_{(Z_0OX_0)_i} = \frac{1}{10} \cdot \sum_{i=1}^{n} \cdot V_i \cdot \frac{\left(R_i^5 - r_i^5 + r_{1i}^5\right) - \left(R_i - r_i + r_{1i}\right)^5}{\left(r_i - r_{1i}\right) \cdot \left(R + r_{1i}\right) \cdot \left(R_i - r_i\right)}. \tag{12}$$

2. Relatively to Y_0Y_0 ($I^V_{Y_0Y_0} = I^V_{Z_0Z_0}$):

$$\begin{aligned} I^V_{Y_0Y_0} = I^V_{Z_0Z_0} = \sum_{i=1}^{n} V_i \cdot \left[\frac{1}{6} \cdot h_i^2 \cdot \left(3 - \frac{r_i + r_{1i}}{R_i + r_{1i}} \right) - x_{0i}^2 \right] + \\ + \frac{1}{20} \cdot \sum_{i=1}^{n} (V_i \cdot \frac{\left(R_i^5 - r_i^5 + r_{1i}^5\right) - \left(R_i - r_i + r_{1i}\right)^5}{\left(r_i - r_{1i}\right) \cdot \left(R + r_{1i}\right) \cdot \left(R_i - r_i\right)} + V_i \cdot x_{0i}^2) - V \cdot x_0^2 \end{aligned}. \tag{13}$$

3. In relation to the point And (centre-of-mass):

$$\begin{aligned} I^V_A = \frac{1}{10} \cdot \sum_{i=1}^{n} \cdot V_i \cdot \frac{\left(R_i^5 - r_i^5 + r_{1i}^5\right) - \left(R_i - r_i + r_{1i}\right)^5}{\left(r_i - r_{1i}\right) \cdot \left(R + r_{1i}\right) \cdot \left(R_i - r_i\right)} + 2\sum_{i=1}^{n} V_i \cdot \left[\frac{1}{6} \cdot h_i^2 \cdot \left(3 - \frac{r_i + r_{1i}}{R_i + r_{1i}} \right) - x_{0i}^2 \right] + \\ + \frac{1}{10} \cdot \sum_{i=1}^{n} \left(V_i \cdot \frac{\left(R_i^5 - r_i^5 + r_{1i}^5\right) - \left(R_i - r_i + r_{1i}\right)^5}{\left(r_i - r_{1i}\right) \cdot \left(R + r_{1i}\right) \cdot \left(R_i - r_i\right)} + V_i \cdot x_{0i}^2 \right) - 2V \cdot x_0^2 \end{aligned}. \tag{14}$$

Table 6. Inertia characteristics of the spathe
Tabela 6. Właściwości inercyjne liściowej pochwy kolby kukurydzy

Number	*m*, kg	*V*, m^3	*x$_0$*, m	$I^V_{X_0X_0}$ kg/m^2	$I^V_{Y_0Y_0} = I^V_{Z_0Z_0}$ kg/m^2	I^V_A kg/m^2
1	0.04	0.00000754	0.062	0.00000221	0.0004856	0.0004856
2	0.05	0.00000633	0.084	0.0000056	0.0014893	0.0014893
3	0.025	0.00000452	0.066	0.00000432	0.0005213	0.0005213
4	0.015	0.00000380	0.041	0.00000257	0.0001843	0.0001843
…	…	…	…	…	…	…

The results of determination of moments of inertia of corncobs spathe are given in the table 6.

CONCLUSION

The derived analytical dependences and computer program developed on their basis tend to simplify calculations and provide extensive information concerning the inertia characteristics of cobs of the studied culture.

REFERENCES

Karpusha 1970. – Карпуша П.П., 1970. Обоснование режима работы початкоотделяющего аппарата кукурузоуборочных машин из условия прочности початков. Сборник – Технический прогресс и перспективы развития сельского хозяйства. "Урожай", Киев.

Kuzenko 2002. – Кузенко Д.В., 2002. Аналіз технологічного процесу і силової взаємодії качанів з робочими елементами качановідокремлювального механізму. Вісник аграрної науки Причорномор'я. вип. 2(16), 233–240. Миколаїв.

Kuzenko 2007. – Кузенко Д.В., 2007. Результати теоретичного дослідження динаміки руйнування обгортки качанів у процесі їх відокремлення від стебел. Вісник Львівського державного аграрного університету: Агроінженерні дослідження. Львів: Львів. держ. агроуніверситет, №11, 84–89.

Kuzenko and Pastushenko 2003. – Кузенко Д.В., Пастушенко С.И., 2003. Теория вибрационного метода отделения початков кукурузы.//Сборник трудов ІУ Международной научно-технической конференции "MOTROL-2003", т. 6, 300–306.

Kuzenko and Vatnukh 2009. – Кузенко Д.В., Вантух З.З., 2009. Напрямки розвитку конструкцій та узагальнені технологічні показники качановідокремлювальних систем.// Вісник Львівського державного аграрного університету: Агроінженерні дослідження. - Львів: Львів. нац. агроуніверситет, №13. т. 1, 147–155.

BADANIA INERCYJNYCH WŁAŚCIWOŚCI KOLB KUKURYDZY

Streszczenie. Przeprowadzono teoretyczną i doświadczalną analizę inercji kolb kukurydzy w czasie ich separacji. Rozpatrzono system kolby kukurydzy poprzez opis jego budowy i parametrów ruchu analizowany w czasie pracy maszyn separujących. Przeprowadzono analizę zastosowania urządzeń separujących, używając trzech metod teoretycznej symulacji. Wyprowadzono formuły obliczeniowe i opracowano odpowiedni program komputerowy ułatwiające obliczeniową analizę inercji kolb.

Słowa kluczowe: maszyna do rozdzielania kolb kukurydzy, szybkość naciągania, moment inercji kolb kukurydzy

Accepted for print – Zaakceptowano do druku: 7.12.2010