INNOVATIVE CONSTRUCTIONS OF CUTTING AND GRINDING ASSEMBLIES OF AGRICULTURAL MACHINERY

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Abstract

This article presents construction of the shear and drum cutting assemblies, as well as the beater shredders which have been commonly used in agrarian machines designed for acquiring or processing material for consumption, fodder and power purposes. Due to the fact of high demand for these working assemblies' power, their new constructional solution has been suggested. Results of experimental studies (bench testing) driving, among the others, to determination of the demand for power at the time of plant materials' cutting and shredding, have also been discussed.

Key words: materials' cutting, materials' shredding, working assemblies of farm machines, drum cutting assembly, shear cutting assembly, beater shredder.

INTRODUCTION

Cutting and shredding assemblies are very important working assemblies of farm machines designed for harvesting and processing of plant material for consumption, fodder or power purposes. According to DULCET AT AL. (2006), the harvested plant material may be further effectively processed and stored. The following machines are equipped with cutting and shredding assemblies: mowing machines, chaff cutters, combine harvesters and all types of shredders. The specific character of their construction and the principles of their operation result, among the others, from the fact that the cutting or shredding process realized by them, concerns plant materials the structure of which is non-homogeneous, and their physio-mechanical properties have not been thoroughly identified.

One of the very important ways of lowering the costs of food, fodder or biomass production is, among the others, reduction of outlays needed for obtaining material for its production. It may be achieved by designing machines, which shall be characterized by low working processes' energy consumption. In case of machines for harvesting and shredding materials like cereals or green fodders, it concerns among the others, the cutting and shredding processes realized by them.

At the Faculty of Mechanical Engineering of the University of Science and Technology in Bydgoszcz, there are being conducted continuous activities aiming at developing of new constructional solutions of the machines' working assemblies. At present, new constructions of working assemblies of agricultural machines, with particular consideration of cutting and shredding assemblies, are being designed, the effect of which are the new shear-finger, drum cutting assembly's constructions and the beater shredder.

MATERIALS AND METHODS

The shear-finger cutting assembly is the basic cutting unit occurring in many agricultural machines, in which cutting elements with crosscut edges participate directly in the process of stalks' or stems' cutting process.

The essence of the traditional construction of the shear-finger cutting assembly consists in the fact that the assembly consists in a movable cutter bar and an immovable finger bar. Fingers tapering towards the front facilitating material's partitioning into portions are fastened to the finger bar. Then, material is cut with the use of scissors fastened to the cutter bar performing the back and forth motion. The side fingers' edges or finger liners fastened to them act as the crosscut edge. Correct contact of the knives to finger liners is guaranteed by buttons screwed down to the finger bar. The exemplary diagram of the shear-finger cutting assembly is presented in Fig. 1. and in Fig. 2 its selected construction in a view is shown.

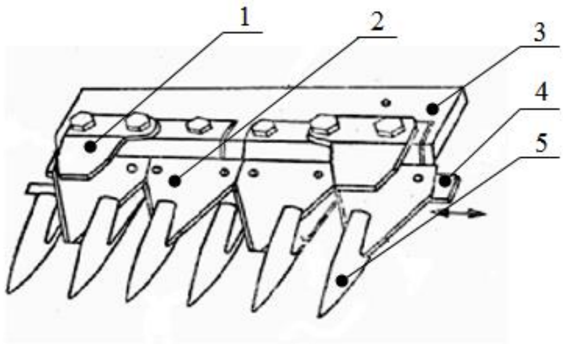

Fig. 1. – Diagram of the shear-finger cutting assembly (KANAFOJSKI, KARWOWSKI, 1980):
1- cutter bar's button, 2 - knife, 3 - finger bar, 4 - cutter bar, 5 – finger

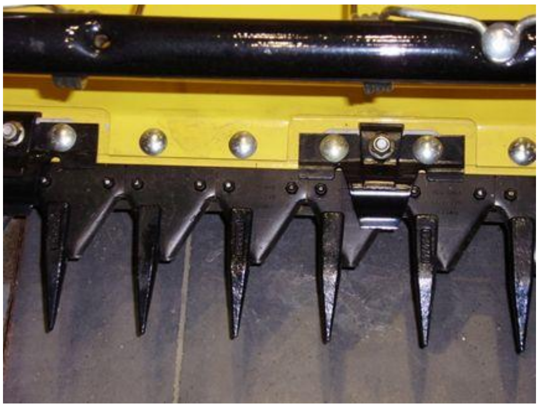

Fig. 2. – Shear-finger cutting assembly of New Holland (own study)

In spite of extensive spreading of agrarian machines equipped with shear-finger cutting assemblies, their construction has not changed considerably for a longer period of time, and in a commonly available, up-dated literature, one may find their single and only conceptual new construction's solutions presented by GUARNIERI AT AL. (2007). Relatively, high energy's consumption is the disadvantage and inconvenience of the existing and commonly used shear-finger cutting assemblies.

Experimental studies conducted by the authors show, that the resistance to dead movement of the cutting assembly has a significant share in the cutting process's power consumption, and the increase of demand for the power in working motion at the time of plant material's cutting amounts only to approx. 10%, what was described by ZASTEMPOWSKI (2010). That drove the authors to construct and to patent the new shear-finger cutting assembly's construction.

The essence of the shear-finger cutting assembly's new construction (Fig. 3) is characterized by the fact, that in place of standard slide buttons, there have been used innovative buttons (of new construction) having an opening in which a roller fastened on a pivot has been inserted. Additionally, a cutter bar of a decreased crosswise section has been used, and the fingers' surfaces that the cutter bar mate with, were subject to the process of electroplating. These processes are to make it possible to lower the demand for power necessary to overcome the friction forces in the cutting assembly's dead movement.

Changes of that type have an important impact on the decrease of the friction forces and inertial forces, what directly translates into the decrease of demand for the shear-finger cutting assembly's power.

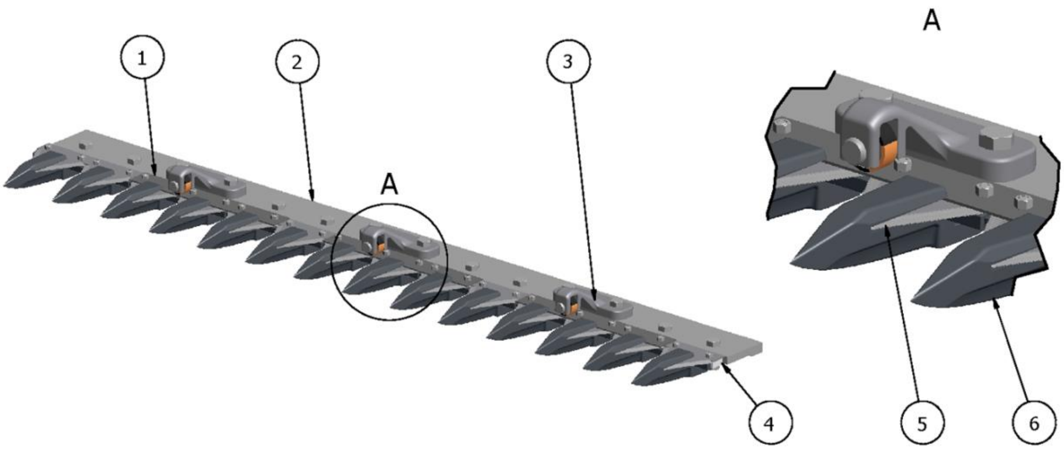

Fig. 3. – New construction of the shear-finger cutting assembly (own study): 1 - tool insert, 2 - finger bar, 3 - button, 4 - cutter bar, 5 - knife, 6 - finger

Calculations of the value of forces acting in the working system and the demand for power on the basis of the calculation tool developed on the basis of own calculation models as well as models presented in literature have been conducted. Calculations were conducted for a traditional construction of a shear-finger cutting assembly for which the demand for power amounts to 15.81 kW and for a new construction of a cutting assembly for which the demand for power amounts to 11.76 kW. ZASTEMPOWSKI AND BOCHAT (2012) wrote on that. The calculations unequivocally prove, that the offered new construction of the shear-finger cutting assembly, due to lower power demand, is characterized by higher functioning effectiveness.

The drum cutting assembly constitutes a basic operating assembly of self-propelled straw cutters, attached or stationary. The task of a drum cutting assembly is cutting of plant material (stalks or stems) into parts (chaff) of determined length.

Application of an assembly of that type in straw cutters makes it possible to obtain the required level of material's shredding. The exemplary construction of the drum cutting assembly is presented in Fig. 4.

Cutting drums may have an open or closed construction. A drum of open construction consists of a shaft on which discs with openings are embedded. Cutter holders are fastened to these discs. Cutting knives are fastened in tool posts. The knives, depending on a drum's construction, may be straight or bended along the screw line, and moreover we can distinguish solid and sectional knives. The cutting drum is positioned in the side plates of the chaff cutter.

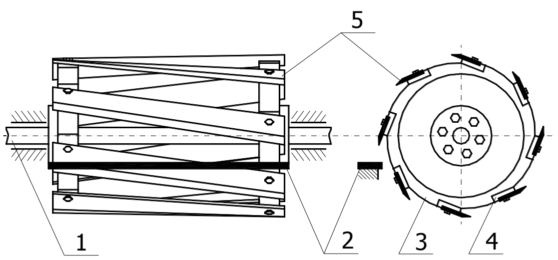

Fig. 4. – Cutting drum of the chaff cutter (BOCHAT, 2010):

1- cutting drum's shaft, 2 - crosscut Edge called shear bar, 3 - cutting drum's disc, 4 - cutter holder, 5 - cutting knife

However, in a cutting drum of a closed construction, on the shaft instead of several discs there is fastened construction in the form of a closed roller on side surface of which there are arranged brackets with cutting discs fastened to them.

In Fig. 5 there is presented the cutting drum of New Holland.

Fig. 5. – Cutting drum of the chaff cutter of New Holland (NEW HOLLAND)

The rules of the drum cutting assembly's operation consist in the fact, that the rotary movement of a cutting drum results in dislocating of cutting knives with them. Knives moving in respect of the immovable shear bar cause, in the first phase – squeeze – pressing of the plant material's layer, and its cutting through in the second stage.

Supplying material between the knife's blade and the counter cutter takes place through the rotational motion of feeding-squeezing rollers, which preliminarily form and thicken the material.

In spite of big popularization of agrarian chaff cutters equipped with drum cutting assemblies, constructions of their cutting assembiles have not been changed lately. From the balance of power (Sankey'a) consumed by a chaff cutter with a drum cutting assembly it results, that the power collected by the cutting assembly clearly predominates over the powers consumed by the remaining working assemblies and amounts to 75-80% , already presented by BOCHAT AND KORPAL (2013). Looking for more energy effective constructional solutions of the drum cutting assembly cutting plant material into chaff, a new design of the cutting assembly has been developed, patented and constructed at the Faculty of Mechanical Engineering WIM UTP.

The essence of the new cutting drum's construction lies in the fact, that it consists of a drive shaft and three discs where the central one has a bigger diameter as compared to the side ones. Knives of blades straight or bended along the screw line in the V arrangement are screwed directly to the discs (Fig. 6). Such construction of a drum makes it possible to cut the material in a diagonally slant manner, the effect of which there should be a considerable lowering of energy consumption of the cutting assembly's operation.

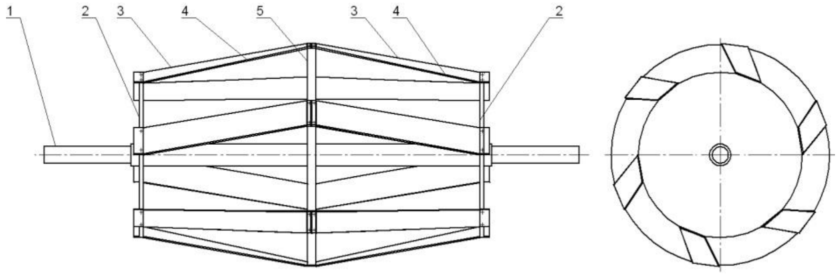

Fig. 6. – New construction of the cutting drum (own study): 1 - shaft, 2 - external discs, 3 - knives, 4 - knives' cutting edges, 5 - central disc

Shredding of cereals' grains is one of the main technological operations performed in the farm-food industry and on farms. Out from may types of shredders, that is: plate grain mills, roller mills, crushing mills and beater shredders, from the point of shredding effectiveness the beater shredders have found the widest application , described by BOCHAT AND WESOŁOWSKI (2009, 2010), DMITREWSKI (1992), KAPUR AT AL.(1990), OBIDZIŃSKI AND HEJFT (2000), OPIELAK (2000), FLIZIKOWSKI AT AL. (2015) AND TOMPOROWSKI AND FLIZIKOWSKI (2013).

However, the present design solutions of the beater shredders are characterised by big shredding energy consumption, as a result of what it is necessary to use power transmission systems of big horsepowers for their power transmission, what has already been described by DMITREWSKI, (1992) and MAGDALINOVIĆ (1989).

The basic elements of a typical beater shredded are a rotor with stiffly fixed beaters, a sieve or a shredder's sieves, a shredding plate or plates and a supporting structure with power transmission system. Low efficiency as compared to energy consumption is a defect and inconvenience of known, traditional design solutions of beater shredders, what has been earlier presented by BOCHAT AND WESOŁOWSKI (2009), KAPUR AT AL. (1990). Most of all it is determined by a rotor's construction, where beaters have the shape of rectangular plates. As the effect of it, under the influence of beaters' strokes, particles of material start moving along the lines similar to a circle. They form a thin layer rotating along an internal perimeter of a shredding chamber what causes that, in spite of sometimes insufficient shredding degree, material has been circulating quite a long time before it goes through the openings in sieves. In Fig. 7a there is presented the traditional rotor of a beater shredder in isometric view.

The essence of a new design lies in the fact, that the working assembly of the shredder consists of the disc rotor embedded on a shaft to which self-aligning beaters are fastened. The beaters have the shape of plates in the form of a circular sector of the obtuse angle of at least 35°, while the beater's fixing hole lies on the circular sector's axis of symmetry close to its arch basis. Such a construction of a beater shredder's rotor causes, that the particles of the shredded material hit by beaters do not move along circular path and do not create a rotating ring, but they move more or less radially with reference to sieves and hit them immediately. It results quicker going of material through the openings in sieves. In Fig. 7b there is presented a new construction of a beater shredder's rotor in isometric view. The presented new design solution of the beater shredder is the subject matter of patent of the RP no 173497 (BOCHAT A.).

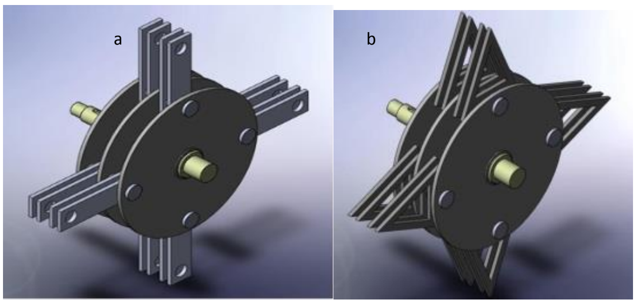

Fig. 7. – The isometric view of the beater shredder's rotor (own study): a - traditional design solution of the rotor (α=0°), b - new design solution of the rotor with beaters in the shape of a circular sector (α=45°)

RESULTS AND DISCUSSION

At the Faculty of Mechanical Engineering of UTP in Bydgoszcz there are also conducted experimental tests concerning the process of cutting with shear-finger cutting assembly. One of the tests' purpose was to determine the total cutting operation $\boldsymbol{L_c}$ performed by the cutter bar.

Determination of dependency was attempted:

$$L_c = f(v_{n\,śr}, v_m). \quad (1)$$

Rye straw (winter rye: Dańkowskie Złote) was the material used for the tests. That material was chosen due to its farming commonness at the territory of Poland.

In order to perform the tests concerning the cutting process with the use of a shear-finger cutting assembly, the authors have designed and constructed a test bed composed of the following elements: a mowing machine ZO34 equipped with a shear-finger cutting assembly fastened on an adjustable frame bearer, feeder of material to be cut, equipped with a pneumatic drive system, power system for power transmission and the cutting assembly's speed control, equipment for the measurement of the turning moment and the rotational speed, equipment for the measurement of the fed material's speed. While designing of the test bed, care was taken of the possibility to change the angle of inclination of the cutting assembly with reference to the cut plants. The general view of the test bed is presented in Fig. 8. The structure of the test bed for examining of the power outlays, reflects the process of plant material cutting conducted in real field conditions, and the additional options of parameters' adjustment and positioning allow for comprehensive tests for different plant materials.

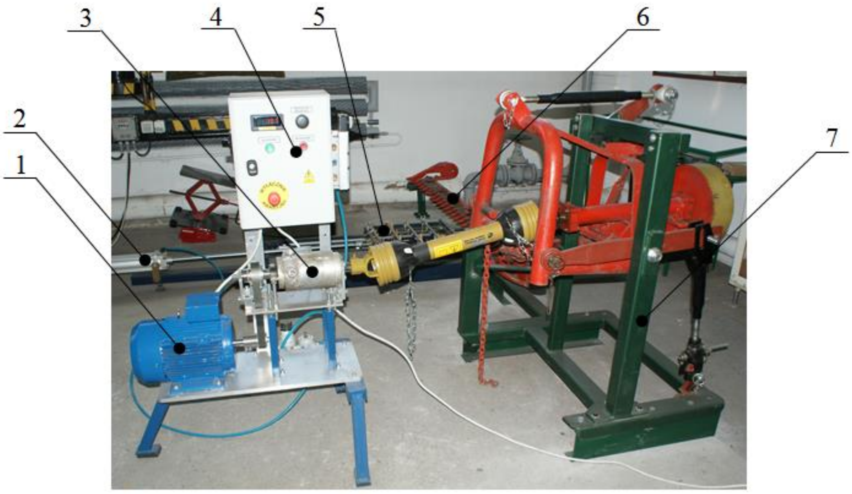

Fig. 8. – Station for examinations of the cutting process with the shear-finger cutting assembly [own study]: 1 - electric motor, 2 - compressed-air engine, 3 - torque measuring shaft, 4 - control and adjustment system, 5 - feeder of material to be cut, 6-mowing machine's cutter bar, 7 - frame bearer with TUZ

In the test bed presented in Fig. 8, the power transmission of the cutter bar's mowing machine is from the electric motor via the power take-off's shaft and the mowing machine's belt transmission. The electric system makes stepless cutter bar's speed adjustment possible. However, the truck's power transmission with material to be cut is realized via the air-operated servo-motor with a system providing constant feeding speed with an opportunity of its smooth change.

As a result of the conducted stand surveys, the total cutting operation of the stalks series L_c (for a single stroke of the cutter bar) depending on the cutter bar's speed $v_{n\,śr}$ and the speed of feeding material to be cut v_m have been determined.

The exemplary results from the conducted surveys are presented in Fig. 9.

From the conducted experimental surveys it results, that the speed of the cutter bar of the cutting assembly and the feeding speed of material to be cut have an important impact on energy consumption of the cutting process of stalk plants performed with the shear-finger cutting assembly.

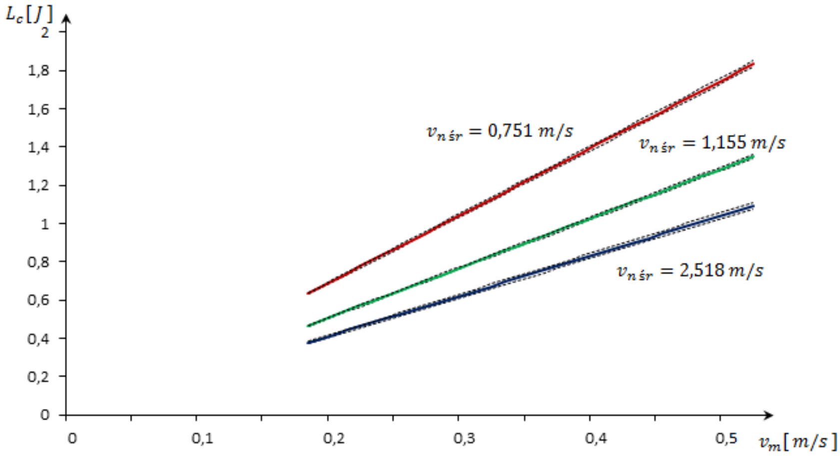

Fig. 9. – Confidence intervals for regression function [own study]

The maximum value of cutting operation $L_c = 1.784$ J was received for the cutter bar's speed $v_{n\,śr} = 0.751$ m/s and the speed of feeding material to be cut $v_m = 0.50$ m/s. However, the lowest value of cutting operation $L_c = 0.330$ J was received for the cutter bar's speed $v_{n\,śr} = 2.58$ m/s and the speed of feeding material to be cut $v_m = 0.18$ m/s. The cutting operation of the single stalk for the accepted speed configurations $v_{n\,śr}$ and v_m amounted respectively to: $L_{cj} = 0.1829$ J and $L_{cj} = 0.3532$ J. Authors of the article have also drawn up the mathematical model of the cutting process, presented by ZASTEMPOWSKI AND BOCHAT (2014).

At the Faculty of Mechanical Engineering of the University of Science and Technology in Bydgoszcz there are also conducted experimental surveys concerning the process of cutting with the drum cutting assembly. During these surveys, there was determined the impact of the selected design features and parameters of a drum cutting assembly on its performance characteristics and the assessment of the possibilities of application of an alternative construction of the drum cutting assembly conducting skew cutting.

Rye straw (winter rye: Dańkowskie Złote) and rape's stalks were used as the material to be cut in the surveys. Material designed for the surveys was selected due to its cultivation's universality at the territory of Poland and its designation for fodder's purposes and, subsequently rape's straw as the energetic material in briquettes' production.

For the purposes of conducting of the surveys concerning the process of cutting with the use of the drum cutting assembly, a second test stand was constructed, which makes it possible to conduct crosswise as well as diagonally slant cutting.

That stand consists of a drum cutting assembly and the measurement devices consisting of: torque measuring shaft with a measuring instrument and a PC control unit of a notebook's type. A test stand is characterised by the fact that it is possible to test cutting assemblies which cut perpendicularly with reference to the feed of the layer cut, and cutting at angle with reference to the direction of the layer's movement. Moreover, it is possible to receive different pressing degrees of the plant material layers which is to be cut.

With the help of the mentioned test stand, it is possible to determine:

- the unit cutting resistance $\boldsymbol{p_c}$,
- the unit cutting operation referred to the area of the cutting surface $\boldsymbol{L_{jS}}$,
- the unit cutting operation referred to the mass of the cut material $\boldsymbol{L_{jm}}$,
- efficiency of the cutting assembly ***W***.

The general view of the test stand is presented in Fig. 10. At the test stand, the drive of the cutting drum's assembly and the assembly of feeding-squeezing rollers is from two independent electric motors via a belt transmission with a cogbelt. In both the cases, there is an option of an independent, stepless adjustment of rotational speed.

The test bed has been equipped with a torque measuring shaft of the measurement range up to 200 Nm, which makes it possible to measure the turning moment on the shaft propelling the cutting drum. It makes it possible to measure energy consumption of the performed process of plant material's cutting into chaff. While designing of the bed, attention was also paid to make it possible to change the positioning of knives' inclination for both the constructional solutions of the cutting drum.

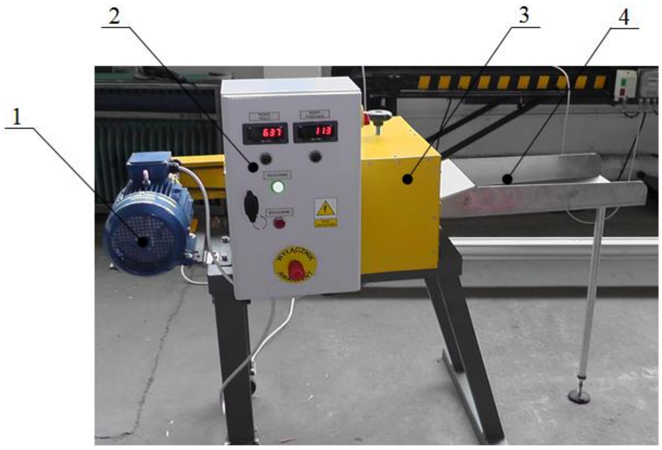

Fig. 10. – Test bed for surveys of the process of cutting with the drum cutting assembly – front view (own study): 1- electric motor with belt transmission, 2 - feed-control system, 3 - feeding-squeezing rollers, 4 - charging gutter

The structure of the test bed for energy inputs' studying reflects the process of plant material's cutting into chaff performed in real field conditions, and additional parameters' adjustment and setpoint options make it possible to conduct comprehensive surveys for different types of plant materials.

The selected results of preliminary studies are presented in Fig. 11 where graphically the influence of the material's feeding angle θ on the unit value of cutting resistance p_c for a determined cutting speed $v_{c.}$ and the material's compacting degree h/h_o, what has been described by BŁASZCZYK (2009).

The conducted experimental studies show unequivocally, that the considerable impact on capacity, energy-consumption of the cutting process with the drum cutting assembly and non-uniformity of the length of the obtained chaff there have: the type of the cutting drum's construction, cutting speed and the cutting material's compacting degree.

It results from the conducted experimental studies, that: application of the cutting drum of new generation as compared to a traditional solution for straw cutting, shall contribute to the increase of the process's efficiency from 5 to 8 %, and in case of new construction of the cutting drum the impact of the degree of material's pressing shall not cause any substantial changes in the cutting process's efficiency. Application of the new construction's cutting drum as compared to the traditional solution, shall contribute to a considerable decrease of the unit energy's consumption (for 25%), together with the increase of the cut material's pressing degree the unit energy's consumption for the material's cutting increases more or less linearly.

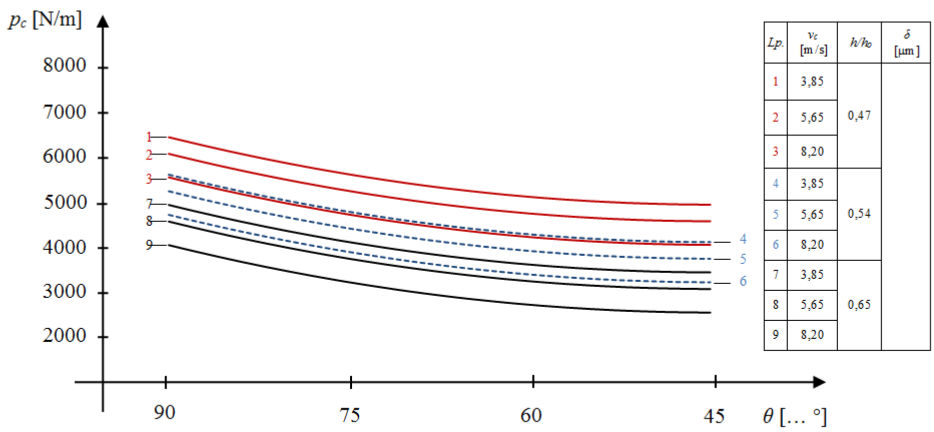

Fig. 11. – Influence of the material's feeding angle θ on the unit value of rye straw's cutting resistance p_c for the cutting speed value v_c, degree of compacting h/h_o and thickness of the blade δ included in the table attached to the diagram (BŁASZCZYK, 2009).

It concerns both constructions of cutting drums, for both the constructions of cutting drums together with the increase of the cutting tangential velocity the degree of chaff length's non-uniformity decreases more or less linearly.

At the Faculty of Mechanical Engineering of UTP in Bydgoszcz there are also conducted experimental surveys concerning the process of material shredding aiming at determination of the shredding process's effectiveness.

For the purposes of the surveys realization, a test stand the view of which is presented in Fig. 12, has been designed and constructed.

A test stand consists of a modified beater shredder type WIR RB-1.3, equipped for the tests with a traditional working assembly of new prototype rotor's designs together with the control-measuring apparatus in the form of the system of electric motor's steering providing fluent rotor's rotations and torque measuring shaft's adjustment for loading's measurement on the rotor's shaft.

Within the frames of the experiment, the triticale's grain was shredded (winter triticale Krakowiak). This material was selected for the surveys because of its cultivation universality and its designation for fodder purposes.

In order to determine shredding effectiveness, the following factors have been assumed to determine:

- shredder's capacity $\boldsymbol{W}$,
- unit power consumption $\boldsymbol{E_j}$,
- share of individual fractions in shredded material $\boldsymbol{X}$.

Selected results of tests presented in Fig. 13.

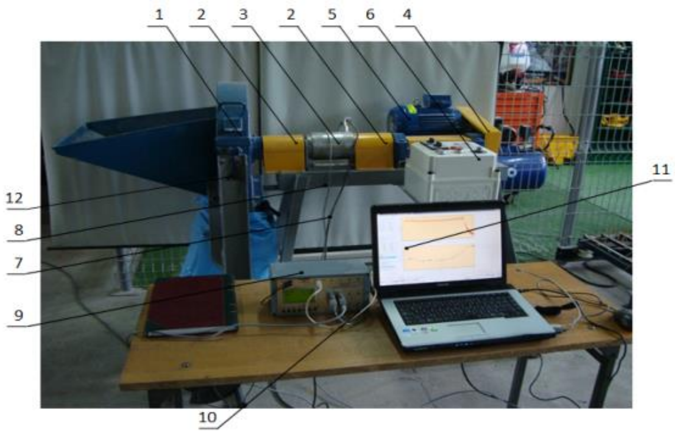

Fig. 12. – View of the test stand (own study): 1 - a modified beater shredder type WIR RB-1.3, 2 - elastic jaw clutch Poly-Norm, 3 - torque measuring shaft with revolution counter type MIR 20, 4 - belt transmission, 5 - electric motor 7 kW, 380 V, 6 - control box with frequency converter Lenze SMD, 7 - transmission conductor of turning moment, 8 - transmission conductor of rotational speed, 9 - two-channel measuring device MW2006-4, 10 - transmission conductor type USB, 11 - computer system with data registration software PP203 and the author's calculation program RB01, 12 - supporting construction.

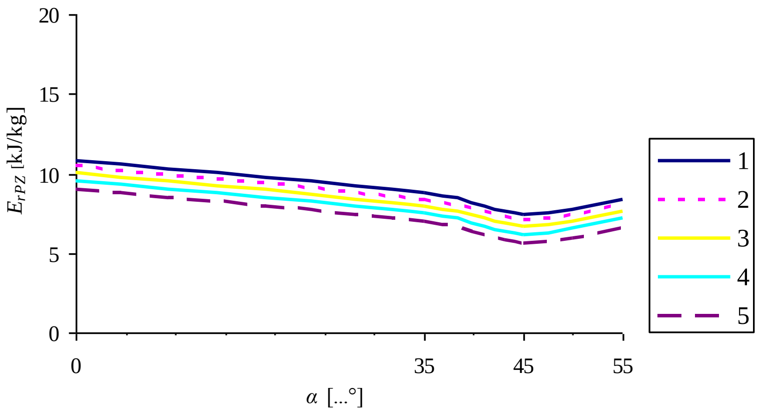

Fig. 13. – Impact of the beaters' angle on the unit power consumption during triticale's shredding for the peripheral speed value of beaters' ends v, beater's gap s = 15 mm and the diameter of openings in sieves d = 5 mm (ZASTEMPOWSKI AT AL., 2015)

It results from the conducted experimental studies, that the following ones have substantial impact on the shredder's output and the unit power consumption as well as the contents of fraction in shredded grains of triticale cereals: the constructional form of a beater assembly, beaters' angle, peripheral speed of beaters' endings, diameter of openings in sieves, beater's gap.

Application in the beater shredder's of a new construction of the rotor equipped with beaters in the shape of a circular sector, resulted in the increase of the shredder's capacity from 11 to 32% and the decrease of the unit power's consumption for shredding from 14 to 46% as compared to traditional constructional rotor's solutions.

Application of a new construction of the beater shredder's rotor, equipped with beaters in the shape of a circular sector, results in the decrease of the dust fraction in shredded cereal, as compared to the traditional design solution.

Application of beaters of the angle α=45° influences:

– the decrease of the dust fraction content from 7.26 to 7.75%,
– the decrease of the fine fraction content from 8.58 to 9.23%,
– the increase of the coarse fraction content from 16.33 to 16.49%;

The conducted analysis of shredding effectiveness has proved, that in case of triticale, application of beaters of the shape of circular sector α=45° , beater gap of the value of s = 10 mm and sieves of the openings' diameter d = 5 mm is the most effective design solution of the beater assembly.

CONCLUSIONS

New design modification developed at the Faculty of Mechanical Engineering of the University of Science and Technology in Bydgoszcz of the working assemblies of machines and equipment commonly used in agriculture, in food industry and while acquiring materials for power purposes at the time of biomass production are presented in this article.

The exemplary results of tests performed at author's test beds have been discussed. All the new designs of working assemblies presented in the article, influence reduction of power's demand during the process of plant material's cutting or shredding. Application of the above discussed constructions may contribute to lowering of the costs of production of food, fodders or power materials' of biomass type.

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