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IDENTIFICATION OF QUASI-STATIC CUTTING FORCE OF TRITICALE-STRAWS FOR DESIGNING USE OF SCISSOR AND FINGER CUTTING SETS

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Abstract

In the article there are presented empirical study results of quasi-static cutting force of triticale-straws. Research conducted on the testing machine INSTRON 8501 showed unambiguously that along with increase of cutting angle relevant to symmetry axis of straws in the range from 0 to 15^0, cutting force value approximately linearly decreases. In that case, it is necessary to check in an empirical way whether mentioned phenomenon occurs with cutting straws by means of scissor and finger cutting set (simultaneous cutting of a few dozen or a few hundred straws). Established change range of straw cutting angle is possible to realize during work of scissor and finger cutting set in field conditions.

Keywords: *scissor and finger cutting sets, cutting, stalk of corn*

1. Introduction

The basic working sets occurring in many agricultural machines are cutting sets of scissor and finger type. They are common in mowers, chaff cutters as well as combine-harvesters. Cutting plant material by scissor and finger cutting set is a special case of mechanical plant material division under the effect of outside forces crossing resistance of intermolecular material cohesion.

The essence of scissor and finger cutting set construction consists in the fact that the set includes a moving knifed slat and immovable finger bar. Cutters riveted to knifed slat have a shape of trapezium. Cutter edges are smooth or they have incisions.

Fingers fastened to finger bar are designed for separating cut material into portions. Fingers have cut-outs that enable plane and manoeuvrable motion of cutters and they also contract forward – in order to separate material easier. In some constructions there are riveted liners to fingers, which form anti-cutting edges. However, in other constructions this function is performed by side finger edges. Proper cutter sticking to liners is ensured by buttons screwed in to finger bar. Furthermore, the knifed slat is leaned on runner [1].

In figure 1 there is presented an exemplary section of scissor and finger cutting set.

Principle of operation of scissor and finger cutting set consists in the fact that fingers enter between cut plants and separate them into portions. Then, individual cutters squash straws or plant stems to side finger edges (anti-cutting edges) and cause cutting plants.

Rational and fast designing of energy-saving scissor and finger cutting sets with great efficiency and stability is conditioned on analytic description of cutting process, occurring in these sets as well as empirical studies of plant material cutting process [1, 2, 3].

Results of *Ł.P. Kramarenko* [2] studies are assumption to conduct additional studies of plant material cutting process. *Ł.P. Kramarenko* has considered different cutting types in aspect of work and cutting resistance. He proved that while oblique cutting of straws and stems (at an angle of 45^0 to its symmetry axis) cutting force, and what follows – cutting work, is lesser in relation to cutting in perpendicular direction.

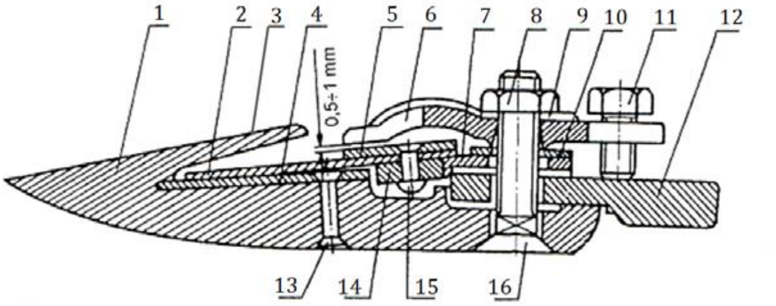

Fig.1. Cross-section of scissors-fingers cutting tool [1]:
1- finger, 2 – knife, 3 – top part of the finger, 4 – blunt edge, 5- plate of the knife, 6 – clamp of the knife slat, 7 – guide of the knife slat, 8 – screw cap, 9,10 – washers, 11-fasten screw, 12- finger bar, 13,15 – fasten rivet, 14 – knife slat , 16 - screw

In that case, it seems rational to study whether such relationship occurs also for angles of straw cutting, e.g.: 5^0, 10^0 and 15^0. Established change range of straw cutting angle results from the fact that it is possible to realize it during work of scissor and finger cutting set in field conditions.

Thus, as a purpose of research there was established empirical determination of triticale-straw cutting force at a different angle in relation to its symmetry axis in quasi-static cutting test as well as indicating possibilities of using these study results on the stage of designing scissor and finger cutting sets.

2. Plan and programme of research

In order to differentiate cutting force in quasi-static test of cutting straw there was planned an experiment. As independent variables in experiment there were established:

- straw cutting angle α,
- geometrical characteristics of stalk section: external diameter d_z and internal diameter d_w.

However, as an independent variable there was established straw cutting force P_{cj}.

The purpose of research was empirical differentiating of cutting force P_{cj} in quasi-static straw cutting test in order to establish relations:

$$P_{cj} = f\,(Fcj,\ \alpha\,), \tag{1}$$

where:
F_{cj} - area of straw section in cutting place,
α - straw cutting angle.

Straw cutting angle was changed in range from 0 to 15^0 , where 5^0 (0^0, 5^0, 10^0, 15^0). The change range of straw cutting angle α established in research was earlier justified.

The research was conducted for the series of 30 selected at random triticale-straws with humidity of 12%.

Constant humidity was guaranteed through constant storage of specimens in air conditioning cabinet. Total measurement number was 120. Prepared specimens of straw elements were 120 mm long each.

Special attention was paid to representative selection of straws for research. The whole population of straws designed for research was divided into five separate groups. From each group there were drawn 6 pieces of straw, resulting in 30 specimens for research. Such process course of random straw selection gave more probability of material representativeness for research.

After drawing straws there were done following measurements: weight of straw, weight of ear, length of individual sections of straw, length of ear, external and internal diameter of second and third straw section. The diameter of second and third straw section was measured in half length, in two perpendicular directions, differentiating the average of measurements. Diameter of the first section was measured after conducting cutting tests. On each straw there was performed four-times cutting research at different angles.

As a result of cutting process, there were obtained four straw sections with length of 10 mm. These sections were cut half in order to measure diameters. Diameters were measured in two perpendicular directions to each other. Exterior d_z and interior diameter d_w was differentiated as the average of eight measurements.

Research material had been prepared in such a way that quasi-static straw separation test was conducted on the section of straw corresponding to cutting height equalling 70 mm. This height corresponds with cutting height being realized by means of scissor and finger cutting set.

3. Research position

Empirical research of cutting force in quasi-static triticale-straw cutting test were conducted on the testing machine INSTRON 8501, belonging to equipment of Accredited Laboratory in Department of Machine Design in the University of Technology and Life Sciences in Bydgoszcz. In experiment there was used a cutting force sensor of own construction, which was fixed in the top handle of testing machine. In the bottom chuck there was fixed a frame of special cutting construction device. The device was designed in order to reflect a single element of scissor and finger cutting set, i.e. a cutter and anti-cutting edge. That is why, there were kept geometrical quantities in the device such as in a typical scissor and finger cutting set. For this reason a cutter and anti-cutting edge were made of original component elements of scissor and finger cutting set.

In figure 2 there was presented the view of device testing cutting force in quasi-static straw cutting test.

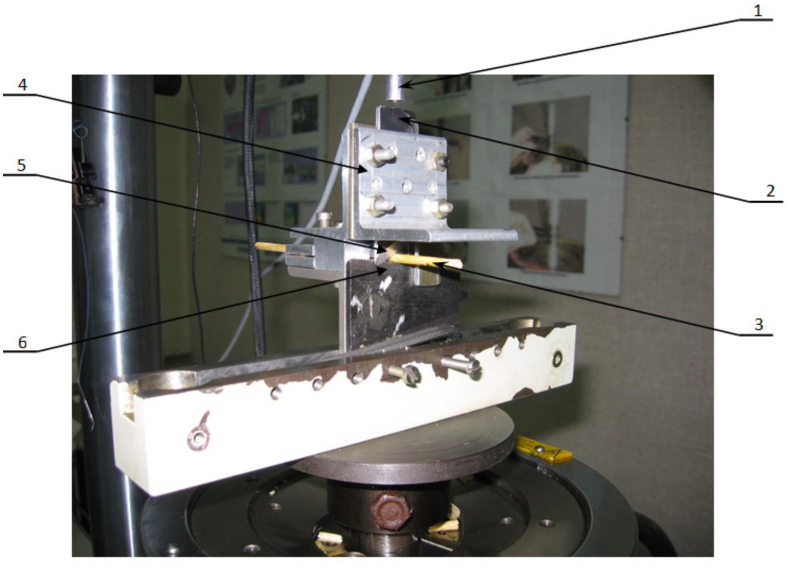

Fig. 2. View of attachment for testing cutting force in quasi-static trial of cutting:
1- mandrel of the force sensor, 2 – knife, 3 – material for cutting, 4 – body of the attachment,
5 – cutting edge, 6 – anti-cutting edge

A cutter in the device was binded to the top fixing handle of testing machine, i.e. force transducer, however an anti-cutting edge was fixed motionless in the frame of device, in the bottom handle of testing machine.

Additionally, the device made fixing the straw possible in such a way that straw cutting angle, i.e. an angle between cutting plane and straw axis, could be changed from 0 to 15^0.

4. Research methodology

Research of quasi-static cutting force was realized in such a way that a testing machine was suitably programmed in order to keep constant feed of top handle with fixed force transducer during surveying measurements. Mandrel of force sensor was influencing the top part of cutter, moving with the speed of 2 mm/s. Stalk of corn were fixed in two special (top and bottom) plates with made groove suitably at an angle of 0^0, 5^0, 10^0 and 15^0. The straw was fixed to such prepared plates and cutting process was realized at mentioned angles. Precision of angle measurement, while preparing plates, was $d\alpha$ = $0{,}5^0$. Cutting force was registered in a computer. Precision of force measurement was dP = 0,01 N.

Exemplar course of cutting force changes in the function of cutter dislocation in straw was presented in figure 3.

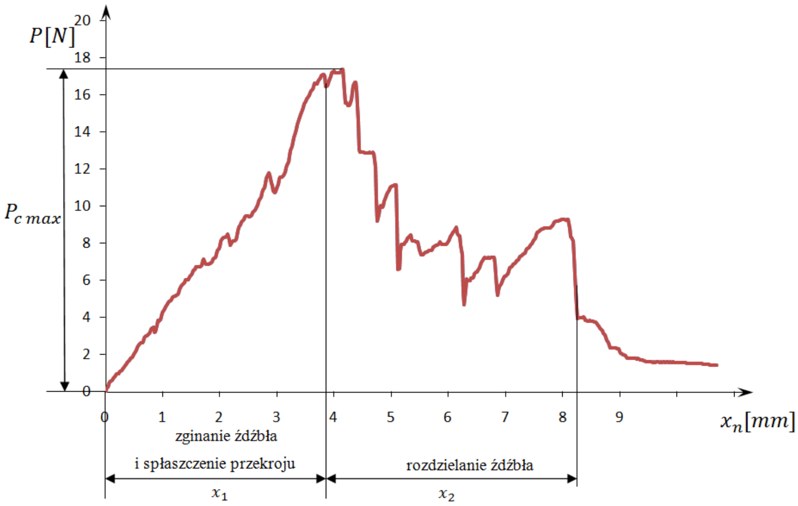

Fig. 3. Phases of cutting process trial

The quasi-static cutting test clearly shows two ranges of process course. In section x_1 the effect of straw deflection occurred and flattening its cross-section that lasts till the moment of reaching force P_{cmax}. Then, in section x_2 phenomenon of separating straw appears. The average force of separating straw is described by the relation:

$$P_{cj} = \frac{1}{x_2} \int_{x_1}^{x_1+x_2} P dx. \tag{2}$$

Cutting force P_{cj} was differentiated on the basis of results from discrete measurements of relation:

$$P_{cj} = \sum_{i=1}^{n} \frac{P}{n}, \tag{3}$$

where:

n – number of measuring points in the range of (x_1, x_1+x_2).

5. Analysis of study results

Conducted empirical studies proved that for all studied cases of cutting a single straw along with increase of straw cutting angle α, cutting force P_{cj} decreases approximately linearly.

In figure 4 there were presented exemplar study results of cutting force in quasi-static triticale-straw cutting test.

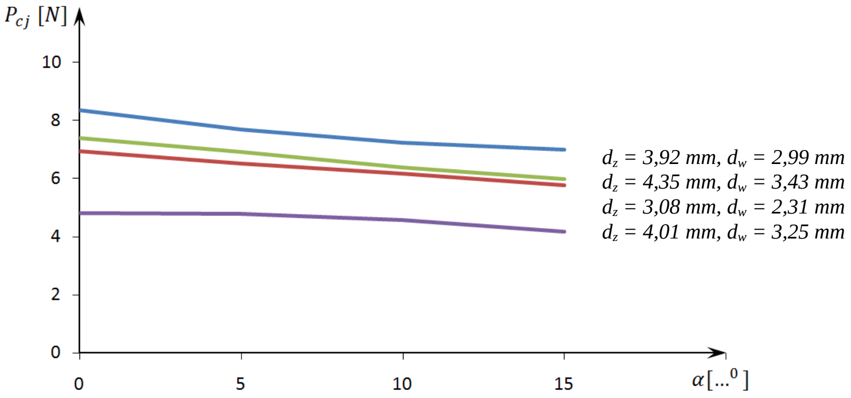

Fig. 4. Graph of the cutting force for different cutting angles of corn stalk to diameter

However, in figure 5 there was presented the dependence of straw cutting force P_{cj} on cutting angle α for three different cutting sections F_{cj}, i.e.: 3,5; 5,5; 7,5 mm^2.

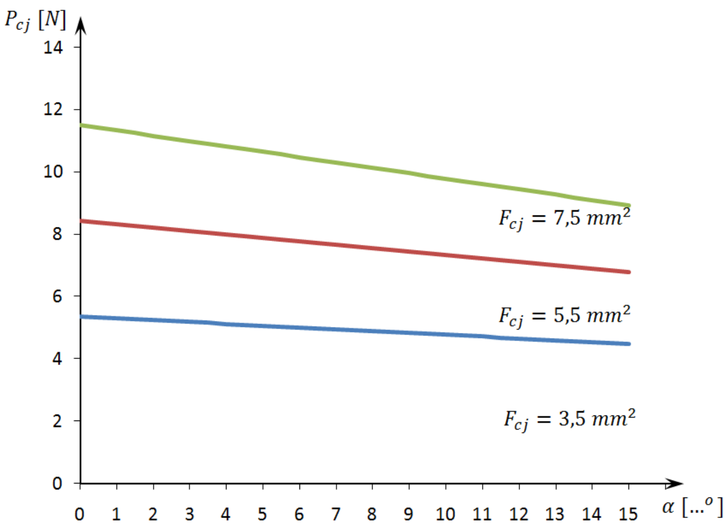

Fig. 5. Graph of the cutting force for different cutting angles and different cross-section area

Conducted analysis of multiple regression proved that static relation between variables of equation (1) has been already described in a satisfactory way on significant level α_{pi} = 0,05 (correlation coefficient R= 0,90) by polynomial of the second degree in the form of:

$$P_{cj} = F_{cj} \, (1{,}5320 + 0{,}0118 \, \alpha + 0{,}0015 \, \alpha \, F_{cj}). \tag{2}$$

In figure 6 there were presented exemplar trusting sections for function regression F_{cj} = 3,5 mm^2.

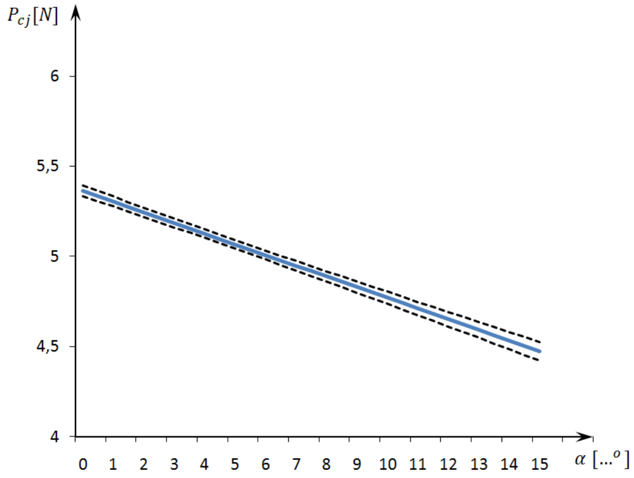

Fig.6. Graph of confidence interval for regression function to corn cross-section F_{cj} = 3,5 mm^2

6. Summary

Conducted empirical studies showed that for all cases of cutting a single triticale-straw, along with increase of straw cutting angle in relation to its symmetry axis (in the range from 0 to 15^0), cutting force in quasi-static test decreases approximately linearly.

In that case, it is necessary to conclude that it is intentional to check in empirical way whether mentioned phenomenon occurs with cutting straws by means of typical construction of scissor and finger cutting set or one should change its construction in order to decrease summary cutting force.

7. Literature

[1] Bochat A., Błaszczyk M., Zastempowski M., *Research issues of single straw and stem cutting process*, Chemical Engineering and Apparatus no. 1/2007.

[2] Chattopahyay P.S., Pandey K.P., *Mechanical properties of sorghum in relation to quasi-static deformation*, Journal of Agricultural Engineering Research, Vol.73, 1999.