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STUDY AND RESEARCH ON ENERGY CONSUMPTION FOR CEREAL GRAIN STRAINS CUTTING

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Abstract: The paper presents the results of the researches on mechanical work for cutting wheat, barley, oats and triticale strains using combine harvesters' finger blade cutting units. In order to obtain these experimental data it has been used a home design laboratory stand, which allows strains cutting at three speeds, two strains positions and three knife blade sharpening angles. Experimental tests have been carried out for cutting units of the most known combine harvesters (SEMA, CLASS, FENDT, JOHN DEERE) at a technological harvesting humidity.
Keywords: strains, cutting force, mechanical work

1. INTRODUCTION

Cutting of plant strains is a basic operation in harvesting technology of cereal grains, being influenced by their physical and mechanical properties, respectively by the constructive features and kinematic status of the cutting units. Reaping machines are designed for cereal grains harvesting, with the possibility to be adapted also to other crops harvesting.

The process of cutting plant strains is complex and requires more or less energy, depending on the factors it influences. As a structure, plant strains are considered viscoelastic materials, dependent on their degree of ripeness and humidity (Dange et al. 2011; Esehaghbeygiat et. al. 2009). In case of cereal grains, strain cutting will be done on the node or between nodes, the necessary energy being bigger when cutting is done on the node (Alizadeh et. al. 2011)

For grain cereals harvesters, finger blade cutting units are exclusively used, with an alternative rectilinear motion. Constructively, they are of a normal cut type, where the blade pitch is equal to the fingers pitch, and the cutting speed does not exceed 3 m/s. As a result of combining the blade motion with the machine movement, during cutting, plants are tilted in both longitudinal and transverse direction, so that plants cutting will be of tilted type.

Finger blade cutting units from the cereal grains harvesters work in different conditions, depending on the crop. Thus, plants density ranges from 200 to 800 plants/m^2, the stalks have a thickness between 1.5 and 4.5 mm, humidity between 10 and 20%, which causes a variation of the force required to cut the strains (Bochat A, 2009).

When designing finger blade cutting units, experimental data are used, both for constructive elements sizing and necessary power needed to drive them. The literature recommends values between 0.58 and 1.18 kW/m, in case of cereal grains harvesting, and from 1.10 to 1.84 kW/m, in case of fodder plants.

In order to reduce energy consumption when cutting plant strains, it is necessary to know how constructive elements and kinematic mode of the knives influence the cutting operation.

2. MATERIAL AND METHOD

For the study of the mechanical work required to cut the strains in some cereal grains, constructional elements of the cutting units from SEMA, CLASS, FENDT and JOHN DEERE harvesters were used. The constructional parameters of the knives are shown in Figure 1 and Table 1.

For the knives equipping SEMA harvesters, three sharpening angles were made: standard at 20^o, 15^o and 10^o.

Wheat, barley, oat and triticale crop strains have been studied, at the time of harvesting, being measured the strain diameter and their humidity.

The cutting operation of the strains was carried out for two positions of the knife towards the strain: cutting by shearing (the knife moves perpendicularly - at 90^0 - towards the longitudinal axis of the strain) and tilted cutting (the knife moves in a tilted direction at 45^0 towards the longitudinal axis of the strain.

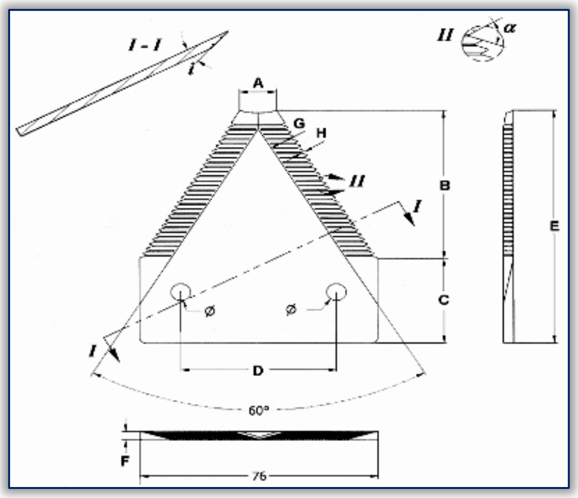

Figure 1 - Geometrical elements of the knife

The knife speed is an important element as regards cutting process. It is known the fact that this is variable because actuators, which transform the rotation movement of the motor shaft in alternative rectilinear motion, cause a velocity of the sinusoidal knife.

For the experimental tests a laboratory stand has been used, whose schematic diagram is shown in Figure 2.

Table 1. Values of the geometrical elements of the knife

Type of knife	A mm	B mm	C mm	D mm	E mm	F mm	G mm	H mm	I 0	α 0
SEMA	7	58	17	50	75	2.3	5	1.45	20	55
CLASS	16	51	33	51	84	2.44	9	1.83	19	31
FENDT	15	50	30	51	80	2.61	7.5	1.75	19	38
JOHN DEERE	13	50	31	51	81	2.67	5.5	1.4	19	46

The stand is made up of: TD – displacement transducer; CTD – displacement transducer converter; TF – force cell; CTF – force cell converter; PAD – data capture board; PC – computer; I – printer; M – monitor; TE – electronic revolution counter/meter; RTV – variable motor controller; U – 24 V supply voltage from the power supply – S; 1 – steering guide rod; 2 – cutting unit; 3 – crank-rod mechanism; 4 – worm gear drive; 5 – direct current electric motor. The force cell type CTS63200KC-250 is connected to a converter type TA4D/2 and through this to a data capture board type NI USB-6008.

The displacement transducer type TLDT 50 is connected to a converter identical with the above one and through this to the data capture board.

The signals taken by those two transducers are converted and processed, the results being displayed on a computer by means of specialized software Lookout HMI-SCADA. (Nuțu G, Cârlescu P., 2017)

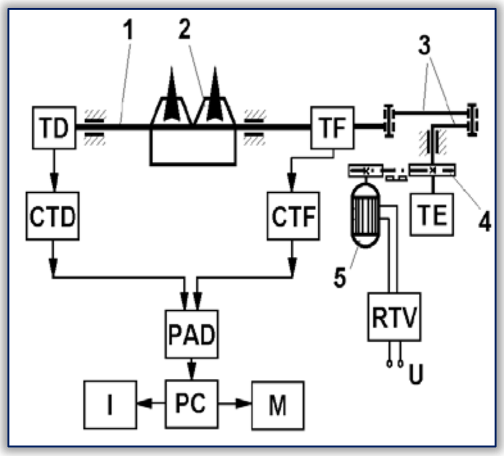

Figure 2 - Stand's schematic diagram

3. RESULTS

The experimental results obtained following measurements performed on laboratory stand are listed in Tables 2 - 6. The figures represent the maximum values of the cutting force as an average of at least six tests, for strains with the same diameter and humidity.

In table 2 are presented the experimental results obtained by measuring the cutting force and the mechanical work necessary to cut wheat strains with a diameter of 4.51 mm and a humidity of 11.7 %. Testes have been carried out for sharpening angles of knife blades of 20^0, 15^0 and 10^0, respectively for knife speeds of 0.2 m/s, 1 m/s and 2 m/s.

Table 2. Variation of mechanical work in cutting wheat strains with SEMA model knives

Sharpening angle (0)	Strain diameter (mm)	Strain humidity (%)	Knife position against strain (0)	Cutting force (N)	Cutting mechanical work (Nm)
Knife speed = 0.2 m/s					
20	4.51	11.7	90	29.55	0.328
			45	21.39	0.283
15	4.51	11.7	90	24.25	0.405
			45	19.35	0.254
10	4.51	11.7	90	18.35	0.313
			45	16.32	0.259
Knife speed = 1 m/s					
20	4.51	11.7	90	23.38	0.259
			45	15.44	0.208
15	4.51	11.7	90	20.16	0.337
			45	15.34	0.202
10	4.51	11.7	90	12.38	0.211
			45	11.44	0.181
Knife speed = 2 m/s					
20	4.51	11.7	90	14.44	0.160
			45	7.04	0.092
15	4.51	11.7	90	11.04	0.184
			45	5.22	0.068
10	4.51	11.7	90	3.59	0.061
			45	3.20	0.500

As expected, the cutting force by shearing wheat strains decreases from 29.55 N, corresponding to a cutting speed of 0.2 m/s and a sharpening angle of 200 to 18.35 N for the same cutting speed conditions and a sharpening angle equal to 100, a trend proved by the cutting mechanical work, respectively from 0.328 Nm to 0.313 Nm. The issue addressed in case of the sharpening angle of the knife blades is the fact that, for small sharpening angles there is a high wear and tear, which required a re-sharpening of knife blades after shorter time intervals, in comparison with the standard angle of 20^0, not being profitable from the economic point of view. To remove this desideratum, it has been performed a titanium nitride coating, procedure known as titanium covering, on the knife blades in a thin layer equal to 3 – 8 μm. It is known from the literature that knife blades are tempered by high frequency currents (CIF), on a distance of 10 – 15 mm from the outside towards the inside, for a hardness of 55 – 60 HRC. Through titanium nitrite coating it is obtained a superior hardness in comparison with that achieved with high frequency currents (CIF).

Table 3. Variation of mechanical work in cutting triticale strains with SEMA model knives

Sharpening angle (^{0})	Strain diameter (mm)	Strain humidity (%)	Knife position against strain (^{0})	Cutting force (N)	Cutting mechanical work (Nm)
Knife speed = 0.2 m/s					
20	6.04	13.2	90	102.9	1.146
			45	77.54	0.789
15	6.04	13.2	90	84.56	1.184
			45	76.42	0.971
10	6.04	13.2	90	60.13	0.940
			45	55.04	0.925
Knife speed = 1 m/s					
20	6.04	13.2	90	97.03	1.080
			45	72.10	0.735
15	6.04	13.2	90	90.12	1.260
			45	71.26	0.905
10	6.04	13.2	90	55.08	0.861
			45	49.48	0.832
Knife speed = 2 m/s					
20	6.04	13.2	90	88.00	0.980
			45	55.86	0.569
15	6.04	13.2	90	80.30	1.125
			45	62.31	0.791
10	6.04	13.2	90	45.26	0.707
			45	41.37	0.695

The same decrease in force, as well as of mechanical work on cutting, occurs as the cutting speed increases, an important factor being also the inertia of the moving knife.

Tilted cutting at which the knife position is displayed for an angle of 5^0 (basically, the strain is tilted) highlights the fact that the cutting force and mechanical work record lower values of cutting by shearing, for similar working conditions.

Experimental tests and results obtained in case of triticale trains cutting (table 3) highlight the same trends as in the case of wheat strains, but because of strains structure and size, they have much higher values. In this case, the degree of wear and tear or blunting of knife cutting edge is much higher than in the case of the wheat strain, reducing the operating time between two re-sharpening procedures.

Experimental tests have also been carried out for knives which are used for cereal grains CLASS, FENDT and JOHN DEERE models, for a standard sharpening angle of 19^0.

Table 4. Variation of mechanical work in cutting wheat strains with CLASS, FENDT and JOHN DEERE model knives

Type of knife	Strain diameter (mm)	Strain humidity (%)	Knife position against strain (^{0})	Cutting force (N)	Cutting mechanical work (Nm)
Knife speed = 0.2 m/s					
CLASS	4.51	11.7	90	23.43	0.308
			45	22.41	0.342
FENDT	4.51	11.7	90	26.49	0.495
			45	24.41	0.337
JOHN DEERE	4.51	11.7	90	19.35	0.241
			45	16.32	0.223
Knife speed = 1 m/s					
CLASS	4.51	11.7	90	18.30	0.240
			45	17.26	0.236
FENDT	4.51	11.7	90	21.44	0.401
			45	16.50	0.248
JOHN DEERE	4.51	11.7	90	14.56	0.181
			45	11.70	0.160
Knife speed = 2 m/s					
CLASS	4.51	11.7	90	9.66	0.127
			45	8.62	0.131
FENDT	4.51	11.7	90	12.36	0.231
			45	6.28	0.094
JOHN DEERE	4.51	11.7	90	4.58	0.057
			45	2.72	0.037

In this case, the tests have been carried out for those three working speeds of the knife, namely cutting by sharing and tilted cutting for wheat crops (Table 4) and triticale crops (Table 5). There are some differences in the cutting force and mechanical work between those three types of knives, depending on the crop and the speed of the knife, so that a certain model or constructive type cannot be established to achieve the lowest values for both crops. Also here, there is a normal trend to decrease those two parameters with the increase of the cutting speed.

Table 5. Variation of mechanical work in cutting triticale strains with CLASS, FENDT and JOHN DEERE model knives

Type of knife	Strain diameter (mm)	Strain humidity (%)	Knife position against strain (⁰)	Cutting force (N)	Cutting mechanical work (Nm)
Knife speed = 0.2 m/s					
CLASS	6.04	13.2	90	92.72	0.962
			45	72.34	0.865
FENDT	6.04	13.2	90	93.74	1.553
			45	80.50	2.047
JOHN DEERE	6.04	13.2	90	89.66	1.523
			45	78.46	1.969
Knife speed = 1 m/s					
CLASS	6.04	13.2	90	87.60	0.909
			45	67.49	0.807
FENDT	6.04	13.2	90	89.09	1.476
			45	75.16	1.912
JOHN DEERE	6.04	13.2	90	84.76	1.440
			45	73.18	1.824
Knife speed = 2 m/s					
CLASS	6.04	13.2	90	78.48	0.814
			45	59.27	0.709
FENDT	6.04	13.2	90	79.40	1.315
			45	65.20	1.658
JOHN DEERE	6.04	13.2	90	75.36	1.280
			45	63.39	1.580

Within the experimental researches, have been carried out also tests of the cutting force and mechanical work for oat and barley strains, for these ones being used SEMA type cutting knives. Experimental data and working conditions are listed as follows in table 6.

Table 6. Variation of mechanical work in cutting oat and barley strains with SEMA model knives, at a 0.2 m/s knife speed

Sharpening angle (⁰)	Strain diameter (mm)	Strain humidity (%)	Knife position against strain (⁰)	Cutting force (N)	Cutting mechanical work (Nm)
Oat					
20	2.82	13.5	90	11.22	0.086
			45	8.16	0.072
15	2.82	13.5	90	6.12	0.067
			45	5.10	0.067
10	2.82	13.5	90	4.08	0.083
			45	3.06	0.062
Barley					
20	3.02	12.3	90	11.22	0.179
			45	9.18	0.118
15	3.02	12.3	90	10.20	0.115
			45	7.14	0.086

The experimental results listed are obtained in the conditions of cutting the strain between nodes, because the positioning in this way is simpler than cutting on node, here the research are to be continued. From the preliminary data obtained, the cutting force of the strains on node, in similar working conditions (cutting speed of 0.2 m/s and cutting by shearing) varies between 61.13 and 68.26 N for wheat, between 18.25 and 26.67 N for barley, between 95.78 and 131.81 N for triticale, and respectively, between 21.39 and 29.23 N for oat.

4. CONCLUSIONS

From the experimental tests it can be seen that the cutting force and the mechanical work for cutting the strains of some cereals depend on the knife geometry (sharpening angle), the fibre-ligneous structure at the time of harvest, marked by humidity, and the knife speed during the cutting.

As the cutting speed fluctuates in time, the maximum cutting force of the strains and displacement of the knife during cutting were calculated on the stand, using transducers connected to a data capture board.

It can be noticed that there is no knife model which has the smallest cutting force, respectively the smallest mechanical work used for cutting, for all the crops analyzed. Also, it can be seen that, SEMA model does not achieve values near to the minimum ones, so it's still necessary to find solutions for energy consumption decrease when cutting plant stems.

Note:

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National Research & Development Institute For Food Bioresources (IBA), University of Agronomic Sciences and Veterinary Medicine Of Bucharest (UASVMB), Research-Development Institute for Plant Protection (ICDPP), Hydraulics and Pneumatics Research Institute (INOE 2000 IHP), National Institute for Research and Development in Environmental Protection (INCDPM), in Bucharest, ROMANIA, between 01–03 November, 2018.

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