Study on the Application of Some Eco-technologies to the Multi-knife Cutting Equipment of a Header

Marius Mocanu [1,*], Ștefan Velicu [1], and Cristian Ionel Păunescu [2]

[1] Doctoral School of Industrial Engineering and Robotics, National University of Science and Technology POLITEHNICA Bucharest, Romania

[2]CESTRIN SA, Bucharest, Romania

Email: contact@romocanu.ro (M.M.); velstefan@hotmail.com (S.V.); paunescu.cristian1996@gmail.com (C.I.P.)

*Corresponding author

Manuscript received May 2, 2025; accepted April 7, 2025; published December 24, 2025.

***Abstract*—This paper presents the application of some eco-technologies to a knife for grassy plants cutting. The aim is to reduce the production and maintenance costs, to protect the environment and to increase the equipment sustainability. The complex machining of the work equipment components using technologies with strong polluting gas emissions (smoke, alkaline vapors, oils loaded with metals, metal dust etc.) entailed studying their replacement with sustainable technologies of nitriding hardening. These sustainable technologies-more environmentally friendly-involve making capillaries on the working surfaces that allow maintaining a wet friction. Experimental investigations after using these eco-technologies proved the positive influence of the cutting equipment behavior during work. They also made possible the optimization of work parameters.**

***Keywords*—Eco-technologies, capillary zone, layer hardened by nitriding, equipment sustainability**

I. Introduction

Over time, man has invented a series of equipment and working techniques to pick/harvest laboriously planted agricultural products. Harvesting, this last process of agricultural production, is the meeting point of all efforts done to gather the fruits of the earth, so necessary for life. The equipment for harvesting agricultural products is among the most complex and expensive systems involved in agricultural production, because these ones include special working parts that carry out technological operations specific to the harvesting process [1]. These parts are operated by electrical, hydraulic sources etc. Also, the subassemblies driving systems can be actuated mechanically/hydraulically/electrically etc. In many cases, it is found that the component of the cutting equipment that could block the agricultural work during harvesting process is the multi-knife cutting assembly [2–4].

This component of the cutting sub-assembly often fails because of:

- Intense mechanical stress;
- Knife cutting edge becomes blunt quickly;
- Cutting table blocking.

To improve the characteristics of the cutting subsystem, it must be taken into account that the plant stems to be harvested are anisotropic materials. The strength of the stems depends on their structure and the moisture incorporated. That is why the cutting operation is made difficult by local crushing of the plants, stretching of the stem, getting caught in the intermediate elements of the subsystem [2]. These inconveniences can be also determined by the way the plant is supported and by the geometrical characteristics of the cutting knives, as shown in Fig. 1.

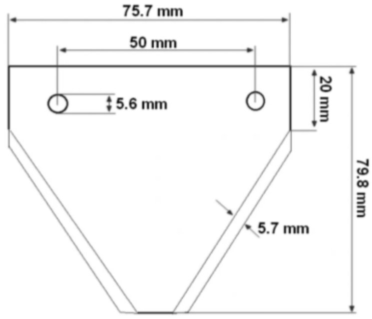


Fig. 1. Geometry of the cutting knife.

II. Current Stage of the Knife Cutting Systems

Currently, the harvesting of grassy plants is performed with cutting systems that include blades with special shapes. The cutting technology is based on a complex working mechanism that enables the sectioning of the stem through the action of the knives active edges [2].

But in the cutting process, the system has to deal with the elasticity of the plant stems, the shape and thickness of these ones. It is known from practice that the knives of the cutting system have a high cutting capacity if they are sharpened at a well-defined angle.

Also, the efficiency of the knife cutting system is conditioned by wear. Thus, the more the active surface of the knife is worn, the more the efficiency of the stem cutting decreases. Premature wear of the knife active surfaces is caused by the moisture of the stem, the density of the stems or even the abrasive particles that appear during the work process (dry friction) [2].

It was observed a characteristic beneficial to the cutting system. It appears while harvesting, mainly in the morning. So, if there is excessive humidity, water is deposited on the surface of the blades, reducing the friction, due to the fact that water acts as a lubricant [4].

The cutting systems of the stems are made in two variants, respectively:

- Shear cutting;
- Inertia cutting.

Taking into account the way the cutting components move, the systems are divided into several groups, as follows:

- Group with cutting systems that have alternate rectilinear motion;
- Group with cutting systems that have rotational movement;

- Group with cutting systems that have uniform linear motion.

This research paper will analyze and propose the updating of the technology for manufacturing the cutting knife and counter knife. The geometry of these 2 components will be made by introducing a more environmentally friendly technology (eco technological process) (Fig. 2).

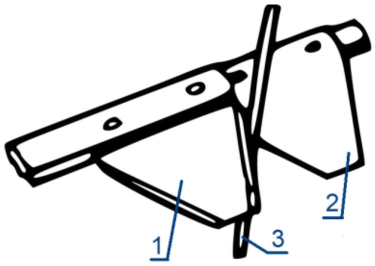


Fig. 2. Shear cutting: (1) knife; (2) counter knife; (3) stem.

The shear cutting system using top knife and finger with counter knife is more often found in the header of a current generation combine harvester. Specialists in the design of agricultural machines recommend that knives with smooth edges be used in the case of green plants; in the case of cereals, the knives must have serrated edges. When making the knives, the average diameter of the plant (grass) stem must be taken into account. Thus, the pitch of the serrations is between 1–1.2 mm for a diameter of 2–4 mm of the stem. As the stem diameter decreases (herbaceous fodder plants), the pitch of the serrations must also decrease until the value equals.

Knives used to cut grass have active surfaces sharpened at an angle of 19–25º. Presently, theses cutting blades are made of quality carbon steel. Their active surfaces are thermally treated (high frequency current hardening) along the entire length of the active part, at a distance of 10–15 mm from the cutting edge, shown in Fig. 3. The hardness achieved by this heat treatment ranges from 30 to 60 HRC (305 to 698 HV), on the commercially available knives we measured an average value of 359 HV0.1 (37 HRC) on the hardened area through this technology, more details on this aspect can be found in chapter IV.

(a) (b)

Fig. 3. Cutting system: (a) knife; (b) counter knife.

In the research work, the main components of the cutting system were analyzed, especially the shear cutting method in grassland crops. The internal and external factors of the grassy plants stem and also the active parts of the cutting system were minimally analyzed. The succinct analysis of the stem of a grassy plant showed zones that can influence the cutting pace. Such zones are the nodes of the stem, the smooth zone and in cross-section, stem with pith(medulla), woody walls, dry zones, wet zones etc. The study takes into consideration that the plant stem is subjected to mechanical forces during the cutting process, associated with deformations, crushing, compression, stretching, bending. It is known that the cutting force decreases if the active part of the knife and counter knife is sharpened (i_c =20º) and the mechanical work leads to low fuel consumption and minimal wear of the components.

III. Theory of the Process of Grassy Plants Stem Cutting

Cutting is the technological process of fragmenting the plant stem. The shear cutting, which is the subject of this study, will be analyzed. The shear cutting uses the cutting knife and counter knife, shown in Fig. 4.

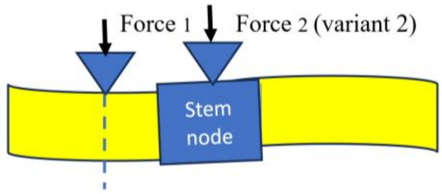


Fig. 4. Frontal cutting of the stem in the smooth area or at the node.

The cutting force is different depending on the zone where the stem is sectioned. Thus, the difference appeared between the two applied forces is obvious. Due to the high hardness in the plant node area, the force applied for cutting will be differentiated, respectively F2 > F1. The frictional forces that occur between the operating components should be also taken into account. Specialized literature highlights that the frictional forces represent 10–15% of the value of the applied force [3]. If the speed of the cutting components is increased, then the friction also increases, leading to premature wear of the knife and counter-knife on the separation finger.

Present research in the field of cutting components takes into consideration the average shearing force at a knife stroke of 10mm, Fig. 5. Thus, the average cutting force is the following one:

$$F_{tm} = F_{tmtot} - F_{gm} \text{ [N]} \tag{1}$$

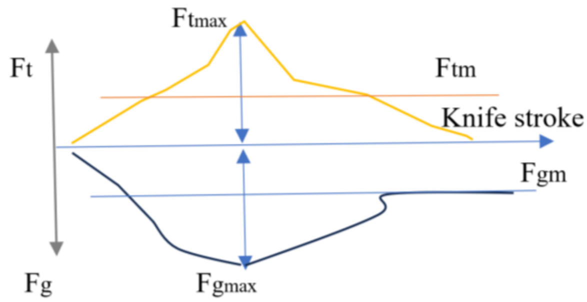


Fig. 5. Average shear cutting force [3].

IV. Functional–Economical Reconfiguration of the Technical Characteristics and Geometry of the Cutting Blade through Less Polluting (Sustainable) Technology

The research is carried out on the knives of the Claas self-propelled combine harvester. The cutting edges of the knives are sharpened under an initial angle (i_c) of 20º–26º, Fig. 6.

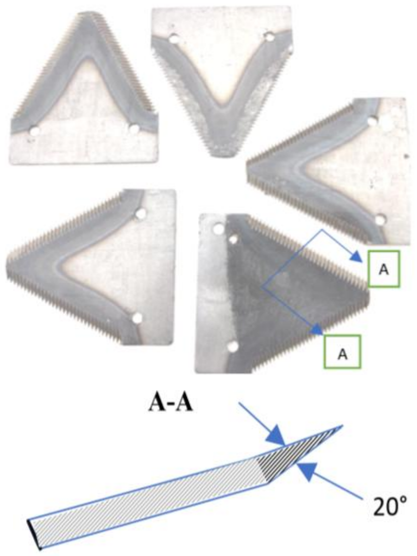


Fig. 6. Knife blades with serrated active edges.

The research focuses on the case when the transverse cut is not made at the stem node. The blades used for cutting the grassy plants were studied. New knife blades were assembled. They were checked after 100 hours of operation. The research paper analyzes the surfaces of the knife and counter knife blades, as follows: analyzing the surfaces before and after 100 hours of operation, measuring the roughness after 100 hours of operation, determining the hardness after 100 hours of operation.

Roughness was measured using the Taylor Hobson surface roughness tester (inductive type). Areas with increased roughness were found. To maintain a constant roughness, the improvement of the characteristics of the cutting blade surface through a sustainable (eco) technology was considered. Plasma nitriding is a less polluting technology. It consists in enriching the surface layer with nitrogen to a depth of 40–250 µm. This technology creates a hard surface layer that helps to reduce friction and will lead to wear decreasing (roughness remains constant) [5, 6]. This technology increases the life of a knife, as it protects the blade against oxidation and improves surface hardness [7]. After studying the knives, more obvious wear was found in the knives placed in the middle of the header. The knives assembled in the extremities of the header were less worn.

Analyzing the values of the forces required for sectioning the stems of grassy plants, Table 1, it is noticed that the forces needed to cut the stem by knife and counter knife are influenced by the hardness of the stem or of its node [3].

Table 1. Cutting forces in cereals. knife blades with IC = 20°

No	Crop	Position*	Area **	Max. [N] force***	Avg. [N] force****
1.	Wheat	vertical 90°	internode	29.55	9.60311
2.			at the node	65.20	13.58652
3.		inclined at 45°	internode	21.39	8.70522
4.	Oat	vertical 90°	internode	11.20	5.89955
5.			at the node	36.67	7.92537
6.		inclined at 45°	internode	9.18	5.52311
7.	Sorghum	vertical 90°	internode	167.08	72.61212
8.			at the node	243.48	114.32535
9.		inclined at 45°	internode	87.62	49.65903

*Stem position related to blade; **Area of stem cutting off;
***Maximum cutting force: ****Average cutting force.

If the sharpening angle (i_c) of the knife-blade is changed to the value of 12°–15°, the cutting forces decrease significantly, Table 2 [3].

Table 2. Cutting forces in cereals. Knife blades with I_C = 15°–12°

No	Crop	Position*	Area **	Max. [N] force***	Avg. [N] force****
1.	Wheat	vertical 90°	internode	18,35	7,17046
2.			at the node	21,14	8,23047
3.		inclined at 45°	internode	16,32	6,93288
4.	Oat	vertical 90°	internode	5,10	1,87795
5.			at the node	6,24	1,93057
6.		inclined at 45°	internode	2,04	1,06104

*Stem position related to blade; **Area of stem cutting off
***Maximum cutting force; ****Average cutting force

After the analysis of the cutting force values, it can be concluded that those ones depend on the type of stem, the sap existing at the time of harvest but also on the sharpening angle of the knife blades. This information can be used to make a knife with the geometry associated to the elements observed. The eco-innovation of the knife geometric surface consists in making capillarity on the flat surfaces of the knife and counter knife.

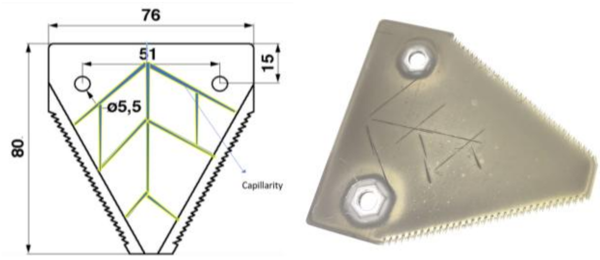


Fig. 7. Cutting blade with capillarity.

The capillarity has the role of maintaining a film of water that will reduce the friction of the abrasions from the knife, counter knife and other components of the system, as shown in Table 3 [3].

Channels with a width up to 2 mm and a depth of 0.8–1 mm are made by pressing on the blade surface before the nitriding treatment (Fig. 7).

It was analyzed the influence of water particles that can appear on the blade as a result of the dew drops or of the air and water bubbles in the stem, when starting the harvesting. The channels on the flat surface of the blade maintain a wet friction between knife and counter knife, leading to a decrease of the wear. Also, the friction between stem and knife has an influence on the wear. The film of water moistens the work area, beneficial for reducing the friction forces. Analyzing the active zones that influence the reaping process, it was found that the size of the angle (i_c) is decisive for the cutting capacity of the knife blades.

Table 3. Roughness after 100 operation hours

Position of knives of the header	Period of operation [hours]	Roughness Ra [µm]
left	new	0.4764
middle		0.4599
right		0.4950
left	100	0.6178
middle		0.6340
right		0,6252

Analyzing the active zones that influence the reaping process, it was found that the size of the angle (i_c) is decisive for the cutting capacity of the knife blades. The most important parameter regarding the changes caused by the wear of the knife-blades is its degree of sharpness [8, 9].

The more intensively a blade wears (becomes blunt), the higher is the coefficient of wear action.

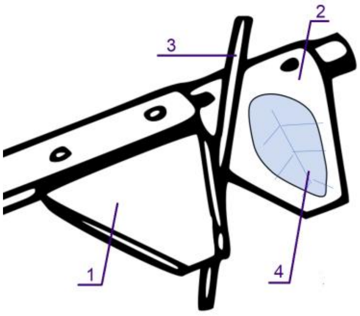
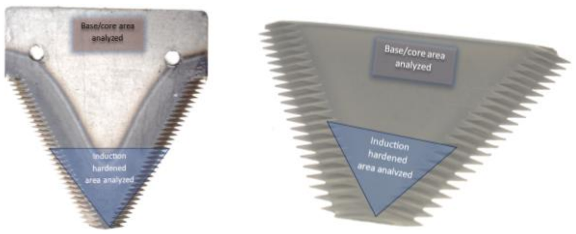


Fig. 8. Formation of liquid films between the cutting edges: (1)knife; (2)counter knife; (3)stem; (4)liquid film over capillarity.

An analysis of the hardness obtained through the present-day classic method (high frequency induction hardening) and through the nitriding technology was carried out. It can be observed that besides the decrease of toxic substances there is a significant improvement in the surface hardness of the knife, (Fig. 9).



(a) (b)

Fig. 9. Heat treatments used: (a) classic induction heat treatment; (b) plasma nitriding treatment.

Before and after treatments, Vickers microhardness indentation measurements were performed by the authors on 5 to 10 different points for each sample using 100 gf (HV0.1) with a dwell time of 10 s, by means of the FM-700 hardness tester (Future-tech Corp, Tokyo, Japan), Fig. 10.

Fig. 10. Hardness tester FM-700 (Future-tech Corp, Tokyo, Japan) and sample image during knife testing.

Following the measurements, differences in hardness are found for the knives subjected to treatments. Thus, the plasma nitriding treatment differs in terms of hardness values compared to the classic heat treatment. Our microhardness indentation measurements revealed an average value of 743 HV0,1 for plasma nitrided knife-blades samples, compared with 359 HV0,1 for the classic heat treated knife-blades samples. Analyzing the expenses in the case of these two technological processes, it is revealed that nitriding expenses could be lower for large production volumes compared with the ones associated with the classic process for which pollution taxes are also paid [10].

Physical parameters represent a significant importance for the phenomenon of knife blades wear, such as: humidity, density of the stem structure, content of abrasive particles resulted from the cutting process etc. It has been highlighted that excessive humidity, followed by water deposition on the blades, acts like a lubricant in the friction with the knife blades. These determinations led to the realization of a capillarity drawing on the blade surface, Fig. 7. The sectioning of the agricultural plants stems through the knife blades action is preceded by the process of prior compression performed by the blade until the destructive force of contact appears on its edge. The nitriding heat treatment reduces blade depreciation due to wear. In the case of the current harvesting system, which uses cutting knives with classic geometry, the coefficient of friction on flat metal plane surfaces without capillarity is higher, leading to wear over time (100 hours of operation). A superficial damage is observed on a certain area of the flat surface of the knives. Three cutting blades (middle) hardened by classic heat treatment, and three other hardened by plasma nitriding and with capillaries were weighed before and after 100 hours of operation. The measured values were entered in Table 4.

Table 4. Determination of mass value for lower cutting knives MIDDLE

Knife	Knife position	Period of operation (hours)	Mass (g) (1)	Mass (g) (2)
1.lower (1,2)	middle	unused	63.8763	64.2014
2.lower (1,2)	middle	unused	64.1976	64.1020
3.lower (1,2)	middle	unused	64.1278	63.7893
1.lower (1,2)	middle	100	63.1026	63.976
2.lower (1,2)	middle	100	63.6541	63.830
3.lower (1,2)	middle	100	63.4964	63.5762

(1) hardened by classic heat treatment,
(2) hardened by plasma nitriding and with capillaries.

The new geometry of the knife and counter knife (Fig. 7), where capillary channels were executed, reduces the friction, because this one occurs at the layers formed between the two surfaces (knife-counter knife), between the fluid molecules. In this case, the friction is low and decreases surface wear more efficiently than in the case of dry friction. Following the new geometry of the knives flat surface (the subject of the research paper: innovative, sustainable eco-technology), the fluid molecules existing between surfaces led to a lower coefficient of friction. The result was the diminution of wear/deterioration-from the mass differences (Table 4) an average mass loss of 2.74 times lower can be found in favor of cutting blades hardened by plasma nitriding and with capillaries. It can be concluded that the wet friction analyzed in this research paper and the plasma nitriding treatment constitute the ways to follow for increasing the reliability of the knives.

V. Conclusion

The theoretical and experimental research carried out by the authors within this scientific approach took place in the laboratories of the Măgurele Research Platform. The multi-professional team (manufacturing engineers, metallurgical engineer, economist), identified a close correlation between the constructive and functional parameters of the cutting equipment – knife and counter knife -and the characteristics of the harvested agricultural crop. This happens in the context of keeping the expenses at least at the same level as the classic technology, but using an alternative treatment with less noxious substances that fall into the categories regulated in the EU for protecting human health and the environment. Also, it resulted from the research that the force required to split the plant stem depends on the constructive parameters of the knife blades, namely the sharpening angles of the edge, surface roughness, resistance to wear, hardness and type of friction. In order to increase the durability and reliability of the components of the cutting equipment in the combine harvesters, the plasma nitriding technical solution was proposed and studied. This solution is more environmentally friendly and brought improvements to the active surfaces at a low cost. The benefits of using nitriding technology give a high hardness of the active zone, resulting in a high resistance to wear by friction and seizing. Fatigue resistance is increased mainly by the development of the surface compressive stresses. Based on field research and the results obtained, the constructive and functional parameters of the cutting blades included in the cereals combine harvesters are optimized. Also, to reduce dry friction by replacing it with wet friction, it is proposed to create capillarity on the active surface of the knife to favor a film of liquid lubrication.

These eco technologies lead to reduced pollution in the manufacturing process as well as reduced cutting force when harvesting cereal crops and the wear of the knives.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

MM carried out the optimization of the parts by making capillary channels on the knife blades, supervised the nitriding treatments and the microhardness tests and wrote the paper; SV conceived and designed the analysis, conducted the research and analyzed the data; CIP carried out the studies for the economic impact and sustainability, contributed to the research plan of the work, to the design of the capillaries and provided the technical documentation and translation services; all authors had approved the final version.

References

[1] CLAAS. [Online]. Available: https://www.claas.co.uk/ accessed on 16.02.2024.

[2] A. Bochat, "Identification of quasi-static cutting force of triticale-straws for designing use of scissor and finger cutting sets," *Journal of Polish CIMAC*, vol. 4-3, pp. 10–27, 2009.

[3] V. Neculăiasa and I. Danilă, *Working Processes and Agricultural Harvesting Machines*, (in Romanian), A92 Publishing House, Iaşi, 1995.

[4] A. Sandru, S. Popescu, and V. Neculaiasa, *Operation of Agricultural Machinery*, (in Romanian), Didactics and Pedagogy Publishing House, Bucharest, 1982.

[5] T. Gläser, S. Bausch, C. Ruset, E. Grigore, T. Craciunescu, and I. Tiseanu, "Combined laser alloying/dispersing and plasma nitriding, an efficient treatment for improving the service lifetime of the forging tools," *Plasma Processes Polym*., vol. 6, pp. S291–S296, 2009.

[6] C. Ruset, E. Grigore, T. Gläser, and S. Bausch, "Combined treatments-A way to improve surface performances," *Journal of Optoelectronics and Advanced Materials*, 2007.

[7] D. Bardac, Şt. Velicu, S. Pălălău, and C. Rânea, *Tool Hardening Technologies*, (in Romanian), Didactics and Pedagogy Publishing House, Bucharest, 1997.

[8] G. Nuțu, "Research on optimization working process for cutting of agricultural plants at the time of harvest," (in Romanian), Doctoral Thesis, "Ion Ionescu de la Brad" University of Agricultural Sciences and Veterinary Medicine from Iaşi, 2020.

[9] V. Scripnic and P. Babiciu, *Agricultural Machines*, (in Romanian), Ceres Publishing House, Bucharest, 1997.

[10] N. Scănteianu and D. G. Galusca, *Technology and control of thermal treatments*, (in Romanian), Technical and Scientific Publishing House, Iaşi, 2003.