UDC 633.522:631.352.5
EDN RAEKGS

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RESEARCH IMPACT OF CUTTING TOOTH SHAPES ON ENERGY CONSUMPTION WHEN CUTTING TECHNICAL HEMP STEMS

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Summary. *The priority direction of domestic hemp breeding today is the creation of new generation technical means for the cultivation of hemp in various areas of its application. Therefore, the development and research of new working bodies for harvesting technical hemp is an important and very urgent task in increasing the level of mechanization of harvesting operations in hemp agriculture. The purpose of the research is to determine the optimal parameters of the cut of the stems of technical hemp, providing minimal energy costs. The research was performed in 2021 in the Laboratory of Agroengineering Technologies at the experimental production of Federal Scientific Center of Bast Crops together with the Department of Power Supply and Electrical Engineering of Tver State Technical University. The work is aimed at creating a mock-up sample of an adapter for cutting stems of technical hemp. For performed research, an experimental installation of a cutting machine with replaceable cutting segments was constructed. For the operation of the installation with the possibility of electric motors soft start and speed control, a basic power supply scheme has been developed. The cut of stems with toothed segments in the shape of a circle, parabola and rounded trapezoid was studied at different levels of variation of factors affecting energy consumption. The consumed power was determined by a digital measuring device SHM-120. We determined thatshape of the cutting edge has the greatest impact on the energy consumption during cutting. It was found that the cleanest and highest-quality cut is performed by segments with a parabolic shape of the tooth, as well as the shape of a circle. At the same time, the minimum energy consumption is 102 and 122 W, respectively. According to the research results, optimal parameters that ensure minimal energy consumption for cutting technical hemp stems have been determined. They are: teeth profile – circle and parabola; cutting tooth height – 11–15 mm; sharpening angle – 45 degrees; teeth thickness – 2– 2.5 mm; cutting disc rotation speed – 800–900 rpm; the feed rate of the stems – 1.4 m/s; cutting speed – 34–38 m/s. These parameters can be recommended when developing a cutting machine prototype.*

Keywords: *technical hemp Cannabis sativa L., cutting machine, hemp cut, shape of cutting tooth, energy consumption, parameters.*

Для цитирования: *Popov R. A., Krupnov A. V. Research impact of cutting tooth shapes on energy consumption when cutting technical hemp stems // Таврический вестник аграрной науки. 2022. № 2(30). С. 103–110. EDN: RAEKGS.*

For citation: *Popov R. A., Krupnov A. V. Research impact of cutting tooth shapes on energy consumption when cutting technical hemp stems // Taurida Herald of the Agrarian Sciences. 2022. No. 2(30). P. 103–110. EDN: RAEKGS.*

Introduction

Technical hemp (*Cannabis sativa* L.) is a strategic agricultural crop grown in Russia and abroad for the production of hemp fiber, hemp oil, etc. Due to its unique properties, hemp annually acquires new, innovative uses.

Technical hemp stems cutting in the process of harvesting has its own characteristics, which causes certain difficulties in the operation of cutting machines of harvesters. During the period of technical ripeness, a strong bast fiber layer, which has, among others, abrasive

properties, is formed in the structure of the stem [1]. It causes rapid wear of cutting elements, clogging of working bodies and disruption of the technological process. In addition, increased energy consumption and short life of the cutting edges do not meet the increasing requirements for modern harvesting equipment [2–4].

One of the most important and responsible working bodies of hemp harvester is the cutting machine. Currently, the most widely used devices for technical hemp stems cutting are rotary-type ones. They work on the principle of a without-prop cutting and have a number of advantages over other types of devices: high productivity and cutting speed, simplicity of design, etc. [5–9].

Considering the solid structure of the hemp stem, there is a need for continuous improvement of working bodies, the search for new design solutions that provide not only a guaranteed cut of stems, but also a reduction in energy consumption and an increase in the resource of cutting elements. Therefore, the development and research of working bodies for harvesting technical hemp is of great practical importance in the domestic hemp industry and the technical equipment of the sub-sector.

Research objective is todetermine the optimal parameters of technical hemp stems cutting providing the minimum costs of energy.

Materials and methods of research

The researches were performed on the base of the Federal Scientific Center of Bast Crops in 2021.The objects of research are an experimental rotary-type cutting machine, *C. sativa* stems selected (bred) in the Penza division of Federal Scientific Center of Bast Crops. The initial data of the research objects are given in Table 1.

Table 1 – Initial data for experimental research

Parameter		Value
Technical hemp variety		‘Nadezhda’, ‘Lyudmila’
Ecotype		Central Russian
Stem moisture content, %		60.0–70.0
Average height of cut stems, m		1.5
Stems diameter, mm:	minimum	10.0
	maximum	20.0
Fiber content in stems, %		26…34
Type of cutting machine		Rotary
Principle of cutting stems		Without-prop cutting
Shape of cutting tooth (shape of cutting edge)		Circle/parabola/trapezoid
Cutting disc diameter, m		0.8

An experimental installation with replaceable cutting segments of various profiles (Figure 1) was made at the experimental production of the Federal Scientific Center of Bast Crops for the study of without-prop cut of technical hemp stems. The installation (Figure 1) consists of a chassis (frame) 1, a cutting machine including a reduction drive with a transformation of the direction of rotation 2, a cutting disc 3 with replaceable toothed segments 4.The cutting machine is operated by an electric motor 5 with a power of 1.5 kW through a V-belt transmission. The plants are fed to the cutting machine by conveyor 6, where the stems are located in rows and fixed cantilevered in a vertical position, which allows you to simulate a cut of plants in the field. The conveyor 6 is driven by an electric motor 7 with a power of 1.1 kW. The feed rate of the stems is regulated by a frequency converter.

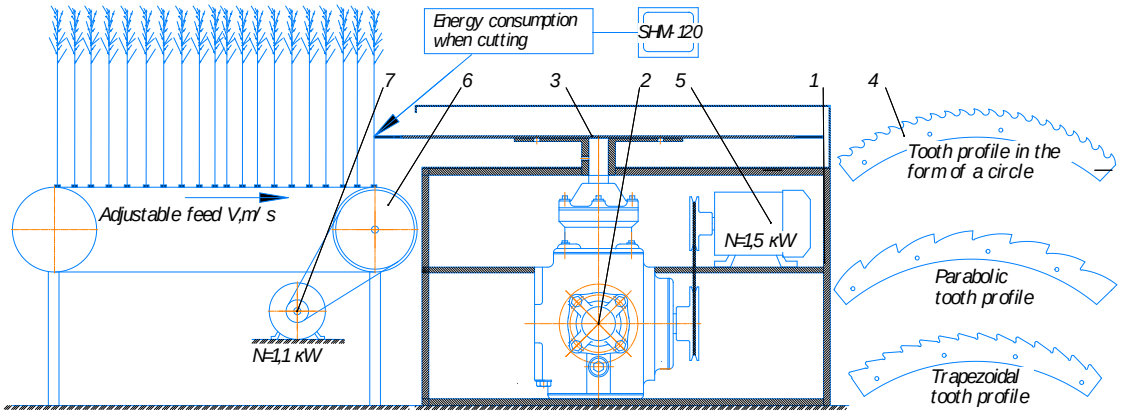


Figure 1 – Diagram of the installation for the study of energy consumption when cutting stems

Note. *1 – chassis (frame); 2 – reduction drive with a transformation of the direction of rotation; 3 – cutting disc; 4 – replaceable toothed segments; 5 – electric motor of the cutting device; 6 – feed conveyor;7 – electric motor of the conveyor drive.*

In the process of research, the effect of such factors as diameter of the stems and their feed rate, speed of rotation of cutting disc, shape of cutting teeth on the energy consumption of the process of hemp stems cutting was considered.

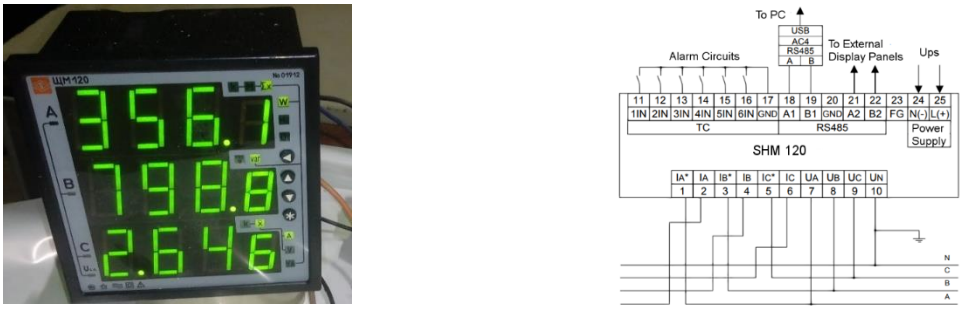
The research was performed according to the methodology of planning a multifactorial experiment of agricultural processes [10]. When compiling the experiment planning matrix, the following factors and levels of their variation were selected (Table 2):

Table 2 – Experiment planning matrix

Factor, unit of measurement	Designation		Levels of variation of factors			Variation interval
	Natural	Coded	Upper	Zero	Lower	
			+	0	–	
Feed rate of stems, m/s	V	X_1	1.4	1.3	1.2	0.1
Tooth profile	profile	X_2	parabola	trapezoid	circle	1

Each of the selected factors X_i varied at three levels: upper (+), lower (–) and zero (main).

For determination of the consumed active power on a cut of stems of technical hemp, a digital multifunctional measuring device SHM-120 (in Russian ЩМ-120) was inserted into the power supply circuit of the installation (into the circuit of the electric motor of the cutting machine) (Figure 2).



A **B**

Figure 2 - General view (A) and connection diagram (B) of measuring device SHM-120

For the operation of the experimental installation, we have specially developed an electrical diagram of its power supply (Figure 3) to study energy consumption in different operating modes with the possibility of soft start of electric motors.

The experimental installation was powered from a three-phase alternating current power grid with a voltage of 380 V and a frequency of 50 Hz. Circuit breakers QF protect the installation and fuses FU protect circuit "frequency converter – electric motor". For soft start of asynchronous motors and speed control, motors are connected to the power grid via frequency converters "VESPER" E2-8300.

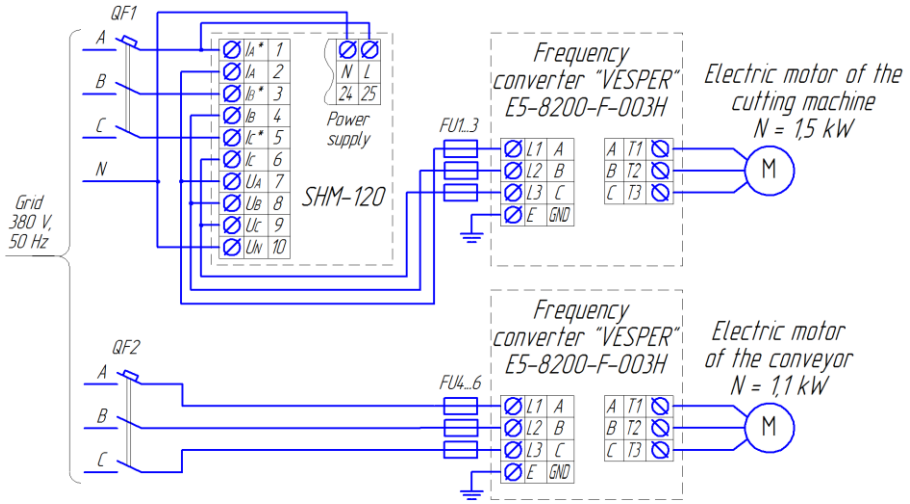


Figure 3 – Electrical power supply scheme of the installation for the study of energy consumption during the cutting of stems

Results and discussion

The main factors determining the quality indicators of cutting stems and energy consumption during the process are the dynamic characteristics of the cutting machine, as well as the optimal parameters of the cutting working body. Therefore, when studying the cut, first of all it is necessary to identify criteria that contribute to minimizing energy consumption [11], the main of which are:

– the resistance of the stems to the cut, which is determined by the technological properties of the plant material and depends on both the characteristics of the stem and the parameters of the cutting working body (cutting angle, blade sharpening angle, linear and angular velocity of the cutting disc);

– the material from which the cutting working body is made, as well as the tooth itself (blade), which affects the durability of work after sharpening and determines the mass of the cutting machine and, accordingly, the moment of its inertia.

Therefore, to optimize energy consumption, the following parameters should be considered: the physical and mechanical properties of the stem, the shape of the cutting tooth, the speed and angle of cutting the stems.

The features of the process of cutting fibrous materials are considered in [12]. For a rotary-type cutting machine, there is a critical cutting speed. When it is exceeded, the impact of the blade on the material being cut occurs and the blade begins to chop, but not to cut the material. This kind of speed is determined by the formula:

$$V_{CRIT} = \frac{120 \cdot n_{bl}}{\pi \cdot d} \cdot \sqrt{\frac{7 \cdot E}{6 \cdot S \cdot (5 \cdot \pi - n_{bl}) \cdot (8 \cdot \pi - n_{bl})}} \quad (1)$$

where n_{bl} – quantity of blades on the cutting disc, pcs.;

d – cutting disc diameter, m;

E – elasticity modulus of the stem material, MPa;

S – hemp stem density, kg/m^3.

Formula (1) shows that the critical cutting speed is directly proportional to the number of blades on the cutting disc and inversely proportional to its diameter.

Federal Scientific Center of Bast Crops is performing research work on the creation of a mock-up sample adapter for cutting stems of technical hemp. Within the scope of this work and taking into account the parameters discussed above, cutting segments with different tooth profiles were developed and manufactured (Figure 4), which will serve as the basis for the manufacture of cutting adapter rotors.

A **B** **C**

Figure 4 – Fragments of cutting segments on a disk with a profile of the cutting edge in the form of a circle (A); parabola (B); trapezoid (C)

According to the results of experimental studies, the following has been determined. Guaranteed cutting of stems is performed by all developed profiles of cutting segments at different levels of varying factors. The cleanest and highest-quality cut is performed by segments with a parabolic tooth shape (profile 2) because of the longer length of the cutting edge exceeding the diameter of the stem, as well by segments with a circle tooth shape (profile 1). The teeth in the form of a trapezoid (profile 3) have a greater impact of the knife on the material being cut and the cut is obtained by chopping.

At the same time, it was discovered that the shape of the cutting edge of the blade has the greatest impact on the energy efficiency of the process, which determines the cutting speed, the sliding coefficient of the blade and the quality of the cut. The results of experimental studies of the cut of stems of technical hemp are presented in Table 3.

Table 3 – Results of research on the power consumed by cutting the stems of technical hemp with teeth of various shapes

Parameter	Tooth profile 1 in the form of a circle			Tooth profile 2 in the form of a parabola			Tooth profile 3 in the form a trapezoid		
	feed rate of stems, V, m/s			feed rate of stems, V, m/s			feed rate of stems, V, m/s		
	1.2	1.3	1.4	1.2	1.3	1.4	1.2	1.3	1.4
thin stems (average diameter – 10 mm)									
Power per cut of stems, *N*, W	125	126	122	102	108	118	138	149	175
thick stems (average diameter – 20 mm)									
Power per cut of stems, *N*, W	176	187	193	181	209	256	190	230	296
Cut quality (visually)	clean cut			clean cut			rough cut (chopping)		

Analysis of the research results shows that with an increase in the feed rate of stems, the power consumption per cut increases. This is due to the fact that elastic deformations occur in the cutting zone, the deformation rate changes the mechanical properties of the material being cut (stem), the total deformation decreases, the coefficient of friction decreases. The dependences of the power expended on the cut of the stem with a different tooth profile, feed rate and different diameter of the stems are graphically depicted in Figures 5–9.

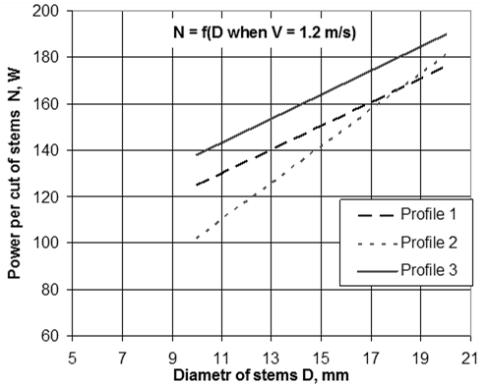


Figure 5 – Dependence of the power consumed on a cut of a stem of different diameters at a constant feed rate of 1.2 m/s and with a different tooth profile

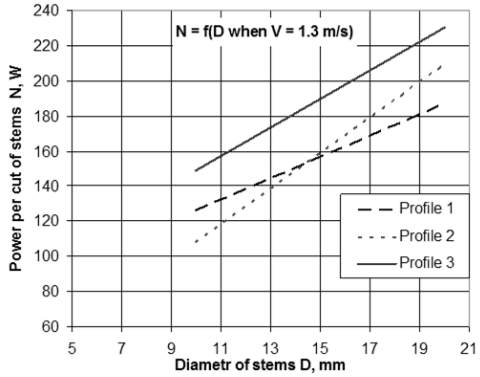


Figure 6 – Dependence of the power consumed on a cut of a stem of different diameters at a constant feed rate of 1.3 m/s and with a different tooth profile

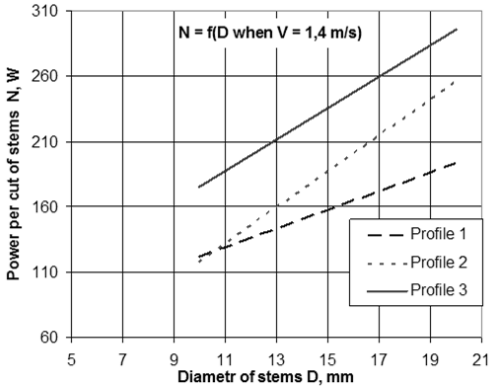


Figure 7 – Dependence of the power consumed on a cut of a stem of different diameters at a constant feed rate of 1.4 m/s and with a different tooth profile

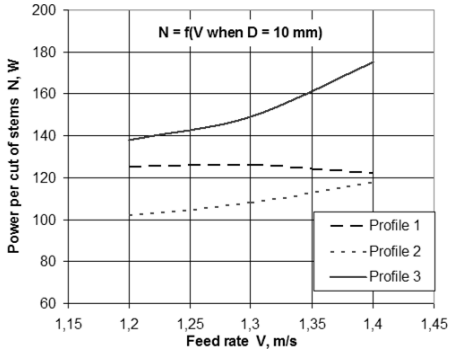


Figure 8 – Dependence of the power consumed per stem cut on the feed rate with different tooth profile and constant average stem diameter of 10 mm

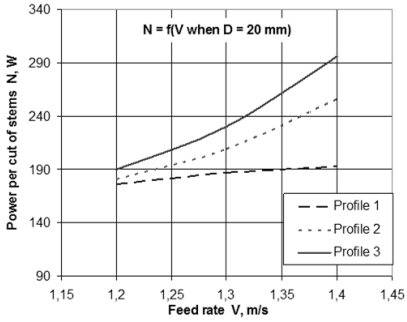


Figure 9 – Dependence of the power consumed per stem cut on the feed rate with different tooth profile and constant average stem diameter of 20 mm

As we have learned from the graphical dependencies, the lowest energy consumption is observed when cutting thin stems by segments with a parabolic and circle tooth shape (102 and 122 watts). This is ensured due to the optimal cutting angle of the stems, the sharpening angle of the cutting edge and high cutting speed.

Conclusions

As a result of the research, the optimal parameters of the cut of the stems of technical hemp, which can be recommended when developing a prototype of a cutting machine, were determined: the profile of the teeth – cutting segments in the shape of a circle (profile 1) and parabola (profile 2); the height of the cutting tooth h = 11–15 mm; the sharpening angle – 45°; the thickness of the teeth t = 2.0–2.5 mm; the rotation speed of the cutting disc n = 800–900 rpm; the feed rate of the stems V = 1.4 m/s; the cutting speed V_{CUT} = 34–38 m/s. It is established that cutting segments with a parabolic tooth shape (profile 2), as well as teeth in the shape of a circle (profile 1) provide the most high-quality cut of stems, thereby using less energy N (102 and 122 watts) due to the shape of the cutting edge.

Work was supported by the Ministry of Education and Science of the Russian Federation within the framework of the State Task of the FSBSI "Federal Scientific Center of Bast Crops" (No. FGSS-2022-0005).

Работа выполнена при поддержке Минобрнауки России в рамках Государственного задания ФГБНУ ФНЦ ЛК (№ FGSS-2022-0005).

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УДК 633.522:631.352.5

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ ФОРМ РЕЖУЩИХ ЗУБЬЕВ НА ЗАТРАТЫ ЭНЕРГИИ ПРИ СРЕЗЕ СТЕБЛЕЙ ТЕХНИЧЕСКОЙ КОНОПЛИ

Реферат. *Приоритетное направление отечественного коноплеводства на сегодняшний день – создание технических средств нового поколения для возделывания конопли по различным направлениям ее использования. Поэтому разработка и исследование новых рабочих органов для уборки технической конопли является важной и весьма актуальной задачей в повышении уровня механизации уборочных работ в коноплеводстве. Цель исследований – определение оптимальных параметров среза стеблей технической конопли, обеспечивающих минимальные затраты энергии. Исследования проведены в 2021 г. в лаборатории агроинженерных технологий и на опытном производстве ФГБНУ «Федеральный научный центр лубяных культур» совместно с кафедрой электроснабжения и электротехники ФГБОУ «Тверской государственный технический университет». Работа направлена на создание макетного образца адаптера для среза стеблей технической конопли. Для проведения исследований изготовлена экспериментальная установка режущего аппарата со сменными режущими сегментами. Для работы установки с возможностью плавного запуска электродвигателей и управления частотой вращения разработана принципиальная электрическая схема питания. Исследовали срез стеблей зубчатыми сегментами в форме окружности, параболы и скругленной трапеции при различных уровнях варьирования факторов, влияющих на энергозатраты. Затрачиваемую мощность определяли цифровым счетчиком мощности ЩМ-120. Определено, что наибольшее влияние на энергозатраты при срезе оказывает форма режущей кромки. Установлено, что наиболее чистый и качественный срез осуществляется сегментами с параболической формой зуба, а также в форме окружности. При этом расход энергии минимален – 102 и 122 Вт соответственно. По результатам исследований определены оптимальные параметры, обеспечивающие минимальные затраты энергии на срез стеблей технической конопли: профиль зубьев – в форме окружности и в форме параболы, высота режущего зуба – 11–15 мм, угол заточки – 45°, толщина зубьев – 2,0–2,5 мм, частота вращения режущего диска – 800–900 об./мин, скорость подачи стеблей – 1,4 м/с, скорость резания – 34–38 м/с, которые могут быть рекомендованы при разработке опытного образца режущего аппарата.*

Ключевые слова: *техническая конопля, режущий аппарат, срез конопли, профиль зуба, энергозатраты, параметры.*

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Дата поступления в редакцию – 23.03.2022.
Дата принятия к печати – 17.04.2022.