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C O N T E N T S

SESSION
“MECHANIZATION IN AGRICULTURE”

SESSION
“CONSERVING OF THE RESOURCES AND TECHNOLOGIES”

Evaluation of the structural change of the grain dryer to technical-economic indicators

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Abstract: Post-harvest grain treatment is today one of the key processes taking place in agriculture-oriented farms. Only cereals deprived of unwanted impurities, dirts and excess water can be optimally stored and later monetized at the highest possible price. It is the reduction of the water content in the grains that is the key factor in their preservation, as the biochemical and bacterial processes will be interrupted, thanks to which the grains can be stored for a long time.
The paper deals with the technical characteristics of the grain dryer Chief CBS 14-6 in the process of drying corn grain in specific conditions in Slovakia, compares various energy sources such as natural gas and waste straw from agricultural production.
***Keywords**:* GRAIN DRYING, DRYER CONSTRUCTION, DRYER ECONOMICS

1. Introduction

The harvesting and post-harvesting of maize represents the final stage of the production process, in which the quality and quantity of the harvested product can still be significantly affected. The harvesting and post-harvesting of maize is accompanied by loss and damage to the grain and thus a reduction in its biological and technological value.

Drying is today the most common method of preserving grains and other agricultural products. The essence of drying is to reduce the water content in the grain or stalk to the optimal storage moisture (Los, Pawlica 2010). The moisture content of long-term stored seed (longer than one year) is 11 to 12% and of long-term stored grain 13 to 14%.

Achieving the required quality of post-harvest maize treatment requires a thorough knowledge of the biological and physical-mechanical properties of the harvested material, working conditions and the impact of working equipment on the processed material. The consequences of maize seed grains, which result in increased waste (split grains) and a reduction in field emergence due to micro-damage to the grains, are particularly serious.

2. Materials and Methods

The CHIEF CBS 14-6 dryer (Fig. 1) is a continuous grain storage dryer. The line is mainly focused on corn processing. The purpose of building a post-harvest line on the stated agricultural enterprise is to ensure post-harvest treatment, dispatch, resp. storage of grains (cereals, corn).

Fig.1 *Chief CBS 14-6*

The purpose of building a post-harvest line on the stated agricultural enterprise is to ensure post-harvest treatment, dispatch, resp. storage of grains (cereals, corn). The arrangement of the machine technology consists of the following composition of the line: - receipt of grains - pre-cleaning, cleaning, drying, dispatch, resp. grain storage. FIG. 2 shows a technological diagram of the line with its technological and storage part. The post-harvest line currently has two CHIEF dryers. The line is used almost all year round, which is made possible by sufficient storage space with a capacity of over 10,000 tons. The CHIEF CBS 14-6 grain dryer has the greatest merit for maintaining the quality of the grains, so we experimentally focused on the evaluation of the quality of work and the operating parameters of this dryer. The set of machines in the line (treatment plant, conveyor, storage tanks) must correspond to the performance parameters of the given dryer. Important parameters of the dryer for the choice in specific conditions are performance, quality of work, energetic and economic parameters.

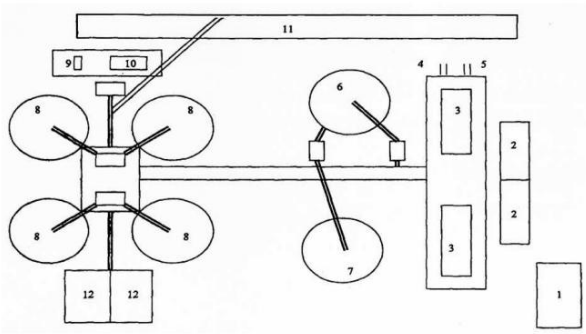

Fig. 2 *Post-harvest line scheme: 1- scale, 2-hopper basket, 3-treatment plants, 4-coarse waste, 5-cleaner, 6,7-dryer, 8-silo, 9-cleaner, 10-trier, 11-floor storage, 12- tanks (handling).*

The reconstruction performed on the model post-harvest line exclusively concerned the dryer and the boiler. This is a replacement of the heating source and related reconstruction work. A heat exchanger is included in the drying medium heating system, so that the dryer meets the HACCP criteria on the safety and safety of dried materials (grains).

The boiler is designed so that it can simultaneously burn straw and unusable waste from cleaning grain at the same time. The straw is burned continuously according to the set mode.

3. Results

Reconstruction of the post-harvest line consisted mainly in changing the source of heating from gas to burning straw bales by installing a boiler burning phytomass (Fig. 4) and also installing a heat exchanger (Fig. 3), as the boiler heats our water and air flows into the dryer.

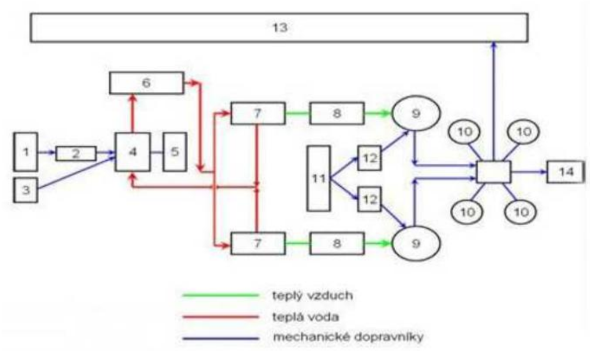

Fig.3 Post-harvest line scheme after treatment: 1-bale storage, 2-dosing device (cutting of packages to the required amount), 3-Dosing device of cleaning waste to the boiler fireplace, 4- Boiler fireplace, 5- Flue gas separator (filter), 6- Tank for heated water (10 m3), 7- Heat exchanger, 8- Fan, 9- Dryer CHIEF, 10- Steel silos with active aeration, 11- Receiving basket, 12- Cleaners, 13- Floor storage, 14- Emptying tank

To assess and evaluate the quality of work of the monitored dryer, we performed control measurements of operating parameters, which are listed in tab. 1. Based on the measured values, we calculated according to the equations in the methodology:

- electricity consumption per tonne of evaporated water, kWh.t-1,
- consumption of natural gas per tonne of dried material, m3 .t-1,
- electricity consumption per tonne of dried material, kWh.t-1,
- cost per tonne of evaporated water, € .t-1,
- natural gas consumption per tonne of evaporated water, m3 .t-1 o.v.

Fig.4 *Boiler room for biomass combustion*

The automatic operation of the combustion device, hot water boiler, fuel dispenser, is ensured by the control automation, PLC boilers by using frequency converters. Boiler control provides:

- control of the hot water boiler room,
- fuel metering according to heat demand,
- protection against overheating,
- cooperation with material dryer,
- data protection,
- 10 program locations for pre-programming of operation types,
- self-defense functions (use of password).

Tab.1 *Technical and economic indicators when using different energy media*

year	Dried quantity, t	Natural gas, m3	electricity kwh	Average of moisture %	Required moisture %	NG/1t m	El/1t kwh	sk/1t 1%moisture
1995	9 271.90	170 870.00	191 670.00	26.8	14	18.42	20.67	8.37
1996	5 647.00	134 007.00	165 784.00	28.58	14	23.73	29.35	9.97
1997	10 181.00	136 962.00	153 371.00	23.00	14	13.45	15.6	9.87
1998	10 010.00	168 904.00	195 239.00	23.00	14	16.87	19.50	12.56
1999	11 000.00	130 987.00	154 140.00	19.85	14	11.91	14.1	13.75
2000	8 580.00	129 708.00	127 926.00	22.57	14	15.12	14.91	11.1
2001	9 638.00	110 705.00	160 000.00	20.8	14	11.48	16.60	16.44
2002	11 880.80	186 934.00	210 408.00	21.52	14	16.17	17.70	17.75
2003	9 933.22	81 401.00	112 200.00	18.88	14	8.19	11.29	19.68
2004	13 767.21	231 793.00	182 549.00	23.22	14	16.83	13.25	16.90
2005	25 013.27	448 726.00	310 700.00	23.68	14	17.94	13.43	21.61
2006	18 145.30	268 567.00	148 649.00	23.5	14	14.80	8.19	25.92
		straw, t				**t**		
2007	14 111.48	401.83	212 606.00	22.52	14	0.030	15.7	9.87 sk
2008	26 364.26	877.00	330 000.00	21	14	0.033	12.51	12.49 sk
2009	20 011.00	880.00	342 208.00	22	14	0.044	17.1	0.49 €
2010	10 200.00	986.00	325 000.00	25.2	14	0.096	31.86	0.68 €
2011	16 507.00	545.00	260 620.00	21	14	0.033	15.78	0.45 €
2012	18 150.00	856.00	310 200.00	21.4	14	0.049	17.9	0.51 €
2013	12.635.80	591.00	124 112.00	23.5	14	0.047	9.82	0.31 €
2014	15 030.00	627.50	254 535.00	22.9	14	0.042	16.93	0.40 €
2015	9 287.00	470.00	110 727.00	23.1	14	0.050	11.92	0.35 €

The authors engaged in the issue say that we divide grain damage into macro-damage, this damage is visible to the naked eye and ranges from 5-10% and to micro-damage, which is visible under a microscope and is usually in the range of 25-30%.

Our corn grain had a damage in the range of 2.95-6.42% after harvest. After drying,

damage increased to 4.69-10.68%, we can say that drying increases grain damage. However, with the right drying process, we can also improve grain quality, such as germination.

Based on the results, we can state that the use of biofuel brings the need to solve certain problems, such as - costly boilers, low year-round hourly usability and its high temperature output, the need to switch from water to air and the need to develop a dryer for such a heat source. The Chief brand on the company in the region of southwestern Slovakia managed to develop such a dryer, which we monitored on the farm in the given years and found that we can save 40% of drying costs every year by using biomass surplus and modified construction design.

CONCLUSION

With the right drying process, we can also improve the quality of dried products, e.g. germination of cereals, the quality of wheat gluten and especially in products intended for feeding, we can achieve significantly higher feed values compared to feed obtained by conventional harvesting by drying, which not only leads to greater losses, but often to a significant reduction in feed value. Due to the great importance of drying and the high energy intensity of drying, it will be necessary to effectively expand the various methods of drying (use more non-traditional forms of energy) plant products, as such a procedure brings a number of economic benefits while increasing the quality of the product.

The aim of the work was to evaluate the work of the CHIEF CBS 14-6 dryer within the chosen farm in the region of western Slovakia, which burns straw.

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Результаты испытаний комбинированного агрегата для предпосевной обработки почвы и посева семян в условиях южного региона Казахстана

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Abstract: Предпосевная обработка почвы и посева в один проход значительно снижают уровень затрат по сравнению с традиционной схемой проведения предпосевной подготовки почвы и сева. Плюсом является сокращение сроков проведения посевных работ в два раза, а так же экономия ГСМ на 20-25% и сохранить влагу в почве и снизить энергозатраты при посеве.
Keywords: ПОЛЕВЫЕ ИСПЫТАНИЯ, КОМБИНИРОВАННОЕ ОРУДИЕ, АГРОФИЗИЧЕСКИЕ ПОКАЗАТЕЛИ, ПЛОЩАДЬ ДЕФОРМАЦИИ, ПЛОТНОСТЬ, ТВЕРДОСТЬ, КРОШЕНИЕ, ГРЕБНИСТОСТЬ ПОЧВЫ.

Введение. Предпосевная обработка почвы является последний и ответственный операцией перед посевом. Проведение предпосевной обработки почвы в мировой практике комбинированные посевные агрегаты с активными и пассивными рабочими органами. Агрегаты с пассивными рабочими органами в основном состоят из культиваторных или рыхлительных лап и прикатывающих катков типа планчатые, трубчатые и кольчато-шпоровые. Посевные агрегаты с активными рабочими органами состоит из активной бороны с вертикальными и горизонтальными рабочими органами.

Чтобы сформировать посевной слой в соответствии с агротехническим требованием необходимо выполнить рыхление, выравнивание, крошение и подуплотнение почвы на глубину заделки семян. Для осуществления благоприятных почв для семян нижний слой должен иметь плотность 0,9-1,3 г/см^3, а в почве должны преобладать комки диаметром 1-25мм (не менее 80%) поверхность поля должна быть выровненной, допустимая гребнистость 3-4см. Зарубежные почвообрабатывающие машины не соответствуют специфическим почвенно-климатическим условиям Казахстана: выносят на поверхность поля крупные комки почвы; не выполняют выравнивание и разуплотнение почв на нужную величину и глубину; не создают фракционный состав почвы, соответствующий агротехническим требованиям, согласно которым содержание мелкокомковатой фракции почвы размером до 20мм должно быть не менее 80%

В Южной зоне Казахстана не распространены посевные агрегаты с активными рабочими органами. Для этого ТОО «НПЦ агроинженерии» разработал комбинированный агрегат для предпосевной обработки почвы и посева семян ФС-2,1 с активными рабочими органами горизонтального расположение Г- образного типа. Сеялка ФС-2,1 обеспечивает обработки почвы и посева в один проход зернобобовых и технических культур по пахотным и по стерневым фонам.

В ТОО «Научно-производственный центр агроинженерии» были проведены лабораторно-полевые испытания макетного образца и исследовательские испытании экспериментального образца.

Методы исследований. При проведении научных исследований по выбору типа, параметров и режимов работы рабочих органов комбинированной машины для предпосевной обработки почвы и посева семян ФС-2,1 использованы классические положения теоретической механики, теории механизмов и машин, механики сплошной среды, земледельческой механики.

При выборе рабочих органов н учитывались особенности почв орошаемой зоны земледелия Юга Казахстана. Анализировались многолетние данные по агрофизическому состоянию почв южной зоны Казахстана в период проведения технологических операций по их обработке. Прежде всего обращалось внимание на динамику влажности, плотность, твердость и крошение.

Для полевых испытаний рабочих органов комбинированного орудия была изготовлена лабораторная установка. Исследовательские испытания макетного и экспериментального образца проводились на полях стационара в ТОО «КазНИИЗиР» согласно следующей нормативной документации:

-ГОСТ 20915-75 «Сельскохозяйственная техника. Методы определения условий испытаний»;
-СТ РК 1560 -2006 Испытания сельскохозяйственной техники. Машины и орудия для глубокой обработки почвы. Методы оценки функциональных показателей.
-СТ РК 1559 -2006 Испытания сельскохозяйственной техники. Машины и орудия для поверхностной обработки почвы. Методы оценки функциональных показателей.
-ГОСТ 20915-2011 «Испытания сельскохозяйственной техники. Методы определения условий испытаний». Межгосударственный стандарт.
-ГОСТ 33687-2015 «Машины и орудия для поверхностной обработки почвы. Методы испытаний». Межгосударственный стандарт.
-ГОСТ 33677- 2015 «Машины и орудия для междурядной и рядной обработки почвы. Методы испытаний». Межгосударственный стандарт.
-ГОСТ 24055-2016 «Техника сельскохозяйственная. Методы эксплуатационно - технологической оценки». Межгосударственный стандарт.
-ГОСТ 12.2.111-85 «Система стандартов безопасности труда (ССБТ). Машины сельскохозяйственные навесные и прицепные. Общие требования безопасности». Межгосударственный стандарт.
Конструкторская документация на экспериментальный образец разработана согласно ГОСТ 2.001-93 «Единая система конструкторской документации. Общие положения».

Результаты и их обсуждение. Для создания оптимальных условий для прорастания семян необходимо довести содержание фракции почвы размером менее 20 мм, как минимум, до 80%, снизить гребнистость поверхности до 3 см, создать плотность почвы в зоне залегания семян не более 1,0г/см3 и сформировать уплотненное ложе для их посева. Плотность почвы после ее обработки в верхнем слое не должна превышать 1,3г/см^3. В связи с этим фрезерные рабочие органы должны обеспечивать заданные агротребованиями показатели предпосевной обработки почв для Юга Казахстана.

Испытания макетного и экспериментального образца Лабораторно-полевые испытания макетного образца комбинированного агрегата для предпосевной обработки почвы и посева семян ФС-1,4 проводился в 2020году на светло-каштановой почве среднесуглинистого механического состава полях ТОО «КазНИИЗиР», на операциях предпосевной фрезерной подготовки почвы и посева семян (рисунок 1).В процессе проведения испытаний были получены следующие результаты:

Условия проведения испытаний были типичны для данной зоны, условия проведения испытаний были типичны для данной зоны. Влажность, плотность и твердость почвы в слое 0-20 см составляли 14,2%; 0,83 г/см3 и 0,9 МПа.

Функциональные показатели приведены в таблице 1. Результаты первичной технической экспертизы показали, что макетный образец комбинированного агрегата соответствуют требованиям технического задания. При внешнем осмотре испытываемого комбинированного агрегата не выявлены дефекты и повреждения. Болтовые соединения не ослаблены, сварные швы выполнены качественно. Качество окраски орудия удовлетворительное. При обкатке машин были проведены регулировки по установке рабочих органов на заданную глубину. Пределы регулировок соответствовали техническому заданию.

Таблица 1 - Функциональные показатели макетного образца ФС-1,4

Показатели	Значения показателей: по техническому заданию	Значения показателей: по результатам испытаний
Предшествующая операция		Боронование
Тип почвы и название по механическому составу	Почва любого типа и механического состава	Среднесуглинистая светло-каштановая почва
Влажность почвы, %, по слоям, см 0-5 5-10 10-15 15-20	30-75% от ППВ	 12,0 13,8 15,1 14,9
Плотность почвы, г/см^3 по слоям, см 0-5 5-10 10-15 15-20	-	0,3 0,7 0,8 0,8
Твердость почвы, МПа в слое, МПа	до 2,5	0,5
Гребнистость поверхности поля, ± см	до ± 5см	
- среднее арифметическое значение, $\overline{X}$ (см) - среднеквадратическое отклонение, ±σ(см) - коэффициент вариации, γ (%)		2,1 1,4 66,6
Глубина заделки заданная см	8	
Глубина заделки фактическая см Среднее значение, $\overline{X}$ (см) Среднее отклонение, ±σ(см) Коэффициент вариации, γ (%)	7,6 0,4 5,3	
Норма высева заданная на п.м/ шт - 5		
Норма высева фактическая на п.м/ шт Среднее значение, $\overline{X}$ (шт) Среднее отклонение, ±σ(шт) Коэффициент вариации, γ (%)	4,4 0,8 18,2	
Интервал между семян-25см		
среднее значение, $\overline{X}$ (см) среднее отклонение, ±σ(см) коэффициент вариации, γ (%)	24,6 1,7 6,9	

Рисунок – 1 Макетный образец ФС-1,4 в работе

По результатам макетный образец комбинированного агрегата для предпосевной обработке почвы и посева семян ФС-1,4 выполняющих операции по предпосевной обработке и посеве семян был работоспособен. Качественные показатели обработки почвы были удовлетворительными. Плотность, твердость, гребнистость почвы и ее крошение после прохода машин соответствовали агротребованиям и техническому заданию.

На основании технического задания, разработана экспериментальный образец машины и результаты полевых испытаний, проведенных в 2021 году, были изготовлены в ТОО «НПЦ агроинженерии» экспериментальный образец комбинированного агрегата для предпосевной обработке почвы и посева семян к тракторам класса тяги 0,6...14 кН; ФС-2,1

Исследовательские испытания Экспериментального образца комбинированного агрегата для предпосевной обработки почвы и посева семян ФС-2,1 на отвальном фоне проводились на полях ТОО «КазНИИЗиР» для предпосевной обработки почвы и посева семян.

Почвенные условия во время проведения испытаний были типичными для данной зоны и сероземных почв. Основные показатели: влажность, плотность, твердость почвы в слое 0-20см соответственно составили 11,4%; 1,12 г/см 1,2МПа. Гребнистость поверхности ± 8,0.

Функциональные показатели работы экспериментального образца приведены в таблице 2

Таблица 2– Функциональные показатели экспериментального образца ФС-2,1

Показатели	Значение показателей	
	По агротребованиям	По результатам испытаний
Агрегат (энергомашина + орудие)		Беларус 80/82 + ФС-2,1
Скорость движения агрегата, км/ч		10
Глубина обработки почвы, см:	-	
- установочная:см - фактическая: см		12,0 11,8
Плотность почвы, г/см^3 по слоям, см		
0-5	до 1,0	0,61
5-10 10-20		0,80 1,20
Твердость почвы, МПа, по слоям, см		
0-5	до 1,0	0,72
5-10		0,89
10-20		1,18
Крошение почвы, % по фракциям, мм		
>50	Содержание фракций почвы размером менее 20мм не менее 70%	-
50-20		2,7
20-10		43
<10		54,3
Гребнистость поверхности поля, ± см	не более 3	2,3

Качественные и агрофизические показатели выполнения технологических операций комбинированными орудиями

Технологические операции	Ширина полосы, см	Глубина обработ-ки, см	Глубина посева семян, см	Количество высеянных семян на п/м рядка, шт
Фрезерование, рыхление полос, посев семян	32,9	10,8	4,8	9,3

Технологические операции по обработке почвы	Сроки выполнения	Агрофизические показатели почвы				
		Гребнистость поверхности, ± см	Крошение почвы, %			
			Размер фракций, мм			
			100-50	50-20	20-10	<10
Фрезерование полос, рыхление полос, посев семян	10.05	2,3	-	2,7	43	54,3

На рисунке 2 показаны посевы кукуруз, проведенные во время испытаний комбинированного агрегата. На рисунке 3 показан экспериментальный образец машины в работе.

Рисунок 2- развитие растений кукурузы

Рисунок – 3 Комбинированная машина ФС-2,1 в работе

Условия проведения испытаний были типичными для данной зоны.С 3 по 10 мая экспериментальный образец испытывалась на операции по предпосевной подготовке почвы и посев пропашных культур. Условия испытаний соответствовали требованиям технического задания. Почвенные условия во время проведения испытаний были типичными для данной зоны и сероземных почв. Основные показатели: влажность, плотность, твердость почвы в слое 0-20см соответственно составили 11,4%; 1,12 г/см 1,2МПа. Гребнистость поверхности ± 8,0.

Функциональные показатели обработки почвы были удовлетворительными и соответствовали агротребованиям. Все полученные результаты по параметрам сформированной полосы, глубине ее обработки, качеству посева семян соответствовали агротребованиям и установочным величинам.Качество обработки почвы машинами было удовлетворительным и соответствовало агротребованиям на технологическую операцию. После прохода плотность почвы в слое 0-20см соответственно составила 0,90 г/см3, твердость 0,94 Мпа. Глубина обработки почвы была стабильной, от-клонения от установочной глубины были незначительными: коэффициент вариации соответственно по машинам равнялся 10,2 %; среднее квадратическое отклонение 0,3см. Содержание мелкокомковатой фракции почвы после прохода составило 97,3%. Содержание фракции размером более 50 мм находилось в пределах допустимых значений (соответственно для машины: 3,7%) как и гребнистость поверхности почвы (2,3см). Поломок и сбоев в работе комбинированных орудий по отвальному фону не наблюдалось.

Заключение по результатам По результатам проведенных НИОКР можно отметить, что макетный образец ФС-1,4 к тракторам класса тяги 0,6 и 14 кН, выполняющих операции по предпосевной обработке и посеве семян был работоспособен. Экспериментальный образец комбинированной машины для предпосевной обработки почвы и посева семян ФС-2,1 устойчиво выполнял технологический процесс и качественные показатели обработки почвы были удовлетворительными. Плотность, твердость, гребнистость почвы и ее крошение после прохода машин соответствовали агротребованиям и техническому заданию. Комбинированного агрегата для предпосевной обработке почвы и посева семян к тракторам класса тяги 0,6 и 14 кН обеспечил лучшее крошение и выровненность поверхности по предпосевной обработке и посеве семян. Энергоемкость на операции по предпосевной обработке почвы и посеву семян была в пределах нормы. Загрузка двигателей тракторов агрегатов в зависимости от скорости движения колебались соответственно в пределах от 75 до 93%. Причем энергоемкость ФС-1,4 была ниже.

В чем преимущества использования: Конструкция комбинированного посевного орудия адаптирована к работе на почвах различного механического состава Юга Казахстана и к его производству на предприятиях сельхозмашиностроения Казахстана. В отличие от однооперационных машин комбинированное орудие на предпосевной подготовке почвы за счет совмещения несколько операций, снижает нагрузку на почву ходовой части машинно-тракторных агрегатов и тем самым препятствует разрушению ее структуры, снижается отрицательное воздействие на агрофизические свойства почвы - воздухо- и водопроницаемость, уменьшается потеря влаги за счет испарения. При работе комбинированного орудия формируется уплотненное посевное ложе и тем самым обеспечивается приток влаги к семенам, стабильная глубина их заделки, что улучшает их всхожесть. Использование комбинированного орудия в перспективных технологиях позволит снизить эксплуатационные затраты и удельные капитальные вложения на 20- 25%.

Какие Ваши планы на будущее: Результаты проведенных исследований будут использованы при проектировании и изготовлении опытного образца комбинированного орудия в этом году. В дальнейшем нашим институтом будет продолжена работа над совершенствованием данного комбинированного орудия ФС-2,1 и подготовлена техническая документация к постановке его на серийное производство.

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Investigation the process of soil seeding during cleaning of rootbull fruits by spiral type cleaner

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Abstract. Cleaning of root crop bodies from impurities during their digging from the soil is a complex and energy-consuming technological process. Therefore, the development of new types of cleaners of root crop pile from impurities, in particular spiral type cleaners, allowing to intensify this process and improve the quality of cleaning is a step to successfully overcome this problem. The paper presents a study of the technological process of sifting soil particles during the cleaning of the heap of root crops with a spiral-type cleaner. In particular, a calculated mathematical model was constructed, which reflects the movement along the spiral of the body cleaner (soil particles) of variable mass. Using the differential equation of volume change, the differential equation of mass change, i.e. the mass that is sifted through the coils of the spiral cleaner was compiled. Based on the theoretical study, it was found that many factors influence the intensity of soil sifting on the spiral separator – the initial mass of particles, the design dimensions of the cleaner, frictional properties of the surface, angular parameters of body placement on the spiral surface and angular velocity of the spiral roller rotation, and the intensity of these parameters has been studied. Using PC, graphical dependences of the intensity of soil sieving on the angle of rotation of the cleaning spiral when changing the angular velocity of the spiral were constructed.

***KEYWORDS**: ROOT CROPS, SPIRAL CLEANER, INTENSITY OF SOIL SIFTING.*

1. Introduction

During the technological process of digging root crops, it is necessary to immediately remove as much soil and other plant impurities from the heap. Purification of the bodies of root crops from impurities is further done by sifting the soil during movements on the cleaning surfaces of the cleaners. However, in the process of mechanized harvesting of root crops after digging up the heap, a significant part of soil impurities is still fed to the working bodies for further cleaning of the bodies of root crops, ie separation with their subsequent transportation. It was found that the content of tubers in the excavated layer is only 3-5%, and the other 95-97% are impurities in the form of fine soil and its lumps, stones, uterine tubers and plant remains [1]. In addition, the high content of impurities in the excavated root of tubers (such as sticky soil) leads to significant losses during storage. Purity of root crops can be achieved by using effective separating working bodies. Many scientists in Ukraine and abroad have worked on the problem of creating effective and reliable potato separators [2-5]. Thus, the effectiveness of the use of heaters of root crops from any impurities can be achieved by using drive cleaning spirals with free cantilever ends, ie spiral separators. However, such spiral separators require theoretical and experimental research in order to improve the quality of their work.

In order to ensure the best intensity of sieving the soil when cleaning the heap on a spiral separator, it is necessary to study the dynamics of the separation process. To do this, consider the movement of the soil heap, ie the body of variable mass on the surface of the spiral roller and determine the influence of factors that most affect the change in mass, ie sifting the soil when cleaning the heap of root crops from impurities.

2. Materials and Methods

To solve this problem, it is necessary to build a mathematical model of the movement of soil particles of variable mass on the surface of the turn of the cleaning spiral in order to study the effect of structural and kinematic parameters on the percentage of sifted soil. To do this, we must first consider the basic tenets of the theory of motion of a variable mass and then build an equivalent scheme. If in the spatial Cartesian coordinate system *xOyz* we will consider a unit volume of a certain size: with length along the axis Ox, width along the axis Oz, height along the axis Oy, then change this volume dW will pass on length, width and height, and at its general change it is necessary to consider action of the separate parameter. To do this, we use the differential equation of change in volume, which has such a general form:

$$dW = \frac{\partial W}{\partial x}dx + \frac{\partial W}{\partial y}dy + \frac{\partial W}{\partial z}dz \,, \tag{1}$$

where W – unit volume of mass; dW – change in unit volume; $\frac{\partial W}{\partial x}$; $\frac{\partial W}{\partial z}$; $\frac{\partial W}{\partial y}$ – gradients of change of unit volume on the corresponding coordinates.

Considering the fact that $m = \gamma_m \cdot W$, where m – mass of the heap;
γ_m – the density of the tuber layer, and accordingly $dm = \gamma_m dW$, then expression (1) will take the following form:

$$dm = \frac{\partial m}{\partial x}dx + \frac{\partial m}{\partial y}dy + \frac{\partial m}{\partial z}dz \,. \tag{2}$$

Analytical expression (2) is a differential equation of change in body weight relative to its geometric parameters (dimensions). Knowing the variable coordinate compared to the initial position and substituting them in this equation, we can theoretically study this change in mass.

Further studies of the process of mass change will be carried out using an extended version of the known formula for sifting grain mass on a keyboard straw shaker. For our case, this equation can be represented as follows:

$$m = m_o(1 - e^{-\lambda L}) \,, \tag{3}$$

where L – mass movement during separation; m_o – the initial mass of the separating heap; e – natural logarithm index; λ – the coefficient of separation of the studied working body, which depends on the parameters and modes of operation, as well as on the properties of the soil (moisture, fractional composition, etc.).

If in our case the mass movement is relative to the three coordinate axes, then $L = \sqrt{x^2 + y^2 + z^2}$. Then, taking into account this, expression (3) takes the following form:

$$m = m_o\left(1 - e^{-\lambda\sqrt{x^2+y^2+z^2}}\right). \tag{4}$$

Next, we determine the partial derivatives of mass by the coordinates included in expression (2). They will be equal:

$$\left.\begin{aligned} \frac{\partial m}{\partial x} &= \frac{m_o \cdot \lambda \cdot x \cdot e^{-\lambda\sqrt{x^2+y^2+z^2}}}{\sqrt{x^2+y^2+z^2}}, \\ \frac{\partial m}{\partial y} &= \frac{m_o \cdot \lambda \cdot y \cdot e^{-\lambda\sqrt{x^2+y^2+z^2}}}{\sqrt{x^2+y^2+z^2}}, \\ \frac{\partial m}{\partial z} &= \frac{m_o \cdot \lambda \cdot z \cdot e^{-\lambda\sqrt{x^2+y^2+z^2}}}{\sqrt{x^2+y^2+z^2}}. \end{aligned}\right\} \tag{5}$$

Substitute the obtained expressions (5) into the differential equation of mass change (2). Then it follows that:

$$dm = m_o\lambda\sqrt{x^2+y^2+z^2}\cdot e^{-\lambda\sqrt{x^2+y^2+z^2}}. \qquad (6)$$

If the left and right parts of the last expression (6) are divided into m_o, then we obtain an analytical expression to determine the percentage of soil sifted by the separator (in fractions):

$$P = \lambda\sqrt{x^2+y^2+z^2}\cdot e^{-\lambda\sqrt{x^2+y^2+z^2}}. \qquad (7)$$

The obtained expression (7), if we substitute in it the corresponding values of the parameters allows us to study the effect of the coordinate change on the percentage of the sieved soil. Determination of the separation coefficient λ we carry out by numerical method by experiment [6, 7]. For this purpose we choose two points at a distance L_1 and L_2 relative to the point of supply and the percentage of sifted soil in them is, respectively P_1 and P_2. Then the expression by which we determine the separation coefficient λ, will take the following form:

$$\lambda = \frac{\ln\dfrac{P_1\cdot L_2}{P_2\cdot L_1}}{L_2 - L_1}. \qquad (8)$$

If we substitute in expression (8) the values of the corresponding points we obtain the separation coefficient, which we substitute in expression (7).

Using PC, construct the percentage surface of the sieved soil according to (7), provided that the separation coefficient $\lambda = 1.1$ (the separation coefficient must be greater than 1.0) (Fig. 1) when changing coordinates x, z from 0 to 0.5 m, and the coordinate y will not be taken into account, assuming that the sieving along this coordinate is not significant and can be neglected.

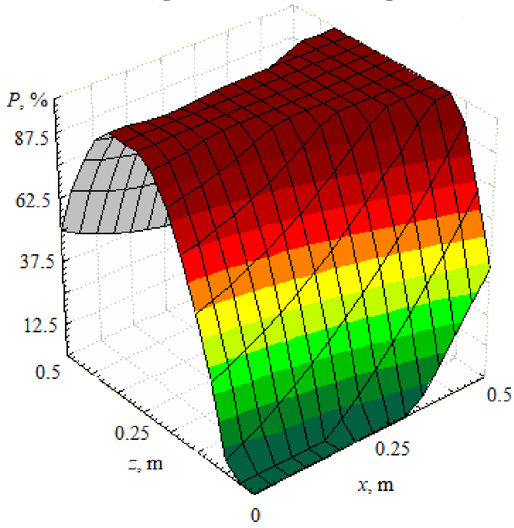

***Figure 1**. Dependence of the percentage of sifted soil (P) from longitudinal (x) and transverse (z) coordinates at the separation coefficient λ = 1.1*

The original analytical expression (8) does not take into account the dynamics of the motion process. To consider the separation in terms of dynamics, we use the differential equation of motion of a body of variable mass on the surface of the cleaning spiral (because a separate volume can be conditionally taken as a body) [7, 8].

We will construct further the equivalent scheme on which we will present the spiral separator in the form of the cylinder with radius R (Fig. 2). To build a mathematical model on an equivalent circuit, we select the elementary volume by mass m. The beginning of the movement on the surface of the cleaning spiral corresponds to the angular parameter ψ_0. The rotation of the cleaning spiral occurs in the direction indicated by the arrow. Body from position A_1 for some time t moves to position A_2. We will show in an equivalent diagram all the forces acting on the body during its motion.

Next, consider this motion of a body of variable mass and make a differential equation of its motion.

In the initial position, the location of the body will be determined by the angle – ψ_o. Its initial mass is equal to – m_o.

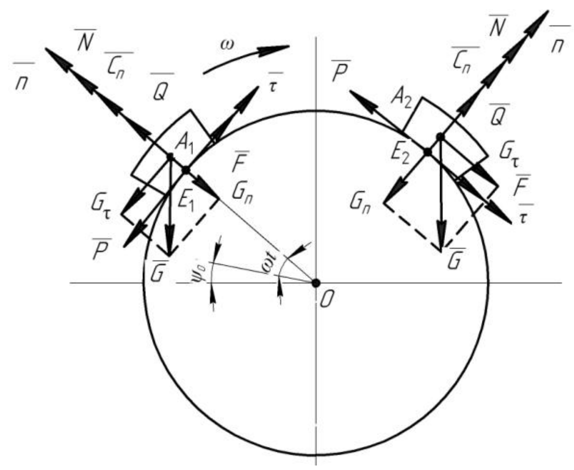

***Figure 2.** Equivalent scheme of motion of a body of variable mass on the surface of a spiral roller (cross section)*

When turning the mass of the cleaning spiral at an angle $\delta\psi$ the current mass value will be equal to:

$$m = m_o - \Delta m = m_o - q'\cdot t,$$

where q' – intensity of soil separation, t – turning time; Δm – change in mass.

The position of the body is determined by the angle $\omega t = \beta$. Define the forces that will act on the system under consideration:

$G = (m_0 - \Delta m)g$ – gravity of a body of variable mass; N – normal surface reaction; $F = Nf$ – the friction force of the mass on the surface of the separator, where f – the coefficient of friction of the sliding heap on the surface of the spiral; $P = \dot{x}\dfrac{d(\Delta m)}{dt}$ – force from the action of mass change; $C_n = (m_0 - \Delta m)\dot{\beta}^2\cdot R$ – centrifugal force; $Q = (m_0 - \Delta m)\cdot\dot{\beta}^2\cdot A\cdot\sin(\psi_0 + \varphi_{Ph} + \dot{\beta}t)$ – force from the acceleration of oscillating motion, where A – amplitude of oscillations; φ_{Ph} – phase shift.

The vector equation of motion of a body of variable mass will look like this:

$$m\frac{d^2\bar{l}}{dt^2} = \bar{G} + \bar{N} + \bar{F} + \bar{P} + \bar{C}_n + \bar{Q}.$$

In projections on the tangent $\bar{\tau}$ and normal $\bar{n}$ we make differential equations of motion of this system. They look like this:

$$\left.\begin{aligned}&(m_0 - \Delta m)\ddot{\beta}\cdot\rho = F\cdot\cos\gamma - G\cdot\cos(\beta_0 + \beta) - P,\\ &0 = N + C_n - G\cdot\sin(\beta_0 + \beta) + Q.\end{aligned}\right\} \qquad (11)$$

From the second equation of system (11) we find the normal reaction of the surface – N. It will be equal:

$$N = G\cdot\sin(\beta_0 + \beta) - Q - C_n. \qquad (12)$$

Substituting in the first equation of the system (11) value N, as well as the value of other forces that make up the right part of it we get:

$$\begin{aligned}&(m_0 - \Delta m)\ddot{\beta}\cdot\rho = f(m_0 - \Delta m)\cos\gamma\times\\ &\times\left[g\cdot\sin(\beta_0 + \beta) - A\cdot\dot{\beta}^2\cdot\sin(\beta_0 + \psi_{Ph} + \beta) - \rho\cdot\dot{\beta}^2\right] - \\ &-(m_0 - \Delta m)\cdot g\cdot\cos(\beta_0 + \beta) - \frac{d(\Delta m)}{dt}\dot{x}.\end{aligned} \qquad (13)$$

Considering that $\Delta m = q't$, and having carried out certain algebraic transformations we will write down the final expression which will express dependence of intensity of separation of a potato heap on constructive and kinematic parameters of a spiral separator:

$$q' = \frac{m_0\dot{\beta}\left\{\ddot{\beta} + f\cos\gamma\left[-g\sin\left(\beta_0+\beta\right) + A\dot{\beta}^2\sin\left(\beta_0+\psi_{\Phi}-\beta\right)+\rho\dot{\beta}^2\right] + g\cos\left(\beta_0+\beta\right)\right\}}{\beta\left\{\ddot{\beta} + f\cos\gamma\left[-g\sin\left(\beta_0+\beta\right)+A\dot{\beta}^2\sin\left(\beta_0+\psi_{Ph}-\beta\right)+\rho\dot{\beta}^2\right] + g\cos\left(\beta_0+\beta\right)\right\}+\rho\dot{\beta}^2\sin\left(\beta_0+\beta\right)+e\dot{\beta}^2\sin\beta}. \quad (14)$$

From the above expression (14) it follows that the sieving intensity on the spiral separator is influenced by many factors – initial mass, construction dimensions (radius of the spiral, angle of inclination of the helix), frictional surface properties, angular parameters of variable mass on the spiral surface and angular velocity rotational movement of the spiral cleaning roller.

3. Results and discussions

We will analyze the influence of these parameters on the intensity of separation by means of direct substitutions in expression (14) of the specific values of the quantities included in it. The values of such values (reflecting the parameters of the spiral separator of our design) are shown in table 1.

Tabel 1. *Constructive and kinematic parameters of the spiral separator, ensuring the efficiency of the screening process of soil*

Dimension	Dimensionality	Value
Coefficient of sliding friction f	–	0.5
Angle of rise of the helical line γ	deg	20
Eccentricity of fixing the spiral e	m	0.005
The initial mass of the heap m_0	kg	80
Amplitude of spiral oscillations A	m	0.01
The initial value of the angular parameter β_0	deg	45
Phase shift ψ_{Ph}	deg	0
Radial mass placement parameter ρ	m	0.15
Spiral rotation angle β	rad	0, 1.047, 2.094, 3.14, 4.187, 5.234, 6.28
The angular velocity of rotation of the spiral $\dot{\beta}$	rad·s^{-1}	0, 10, 20, 30, 40, 50
Acceleration of spiral rotation $\ddot{\beta}$	rad·s^{-2}	0

According to the accepted conditions, when solving expression (14), the intensity of separation Q (kg·s^{-1}) will take the values shown in the graphs of Fig. 3. To obtain the value of the specific intensity of sieving the soil is enough to divide this value by the area of the separator and multiply by coefficients that take into account the filling of the surface of the cleaning spiral, uniformity of mass and volume change along the length of the heap. The obtained graphical dependences indicate that in the second quadrant (on the rise of the mass on the surface of the spiral) the intensity of separation decreases. On the contrary, the growth of separation is investigated by lowering the mass.

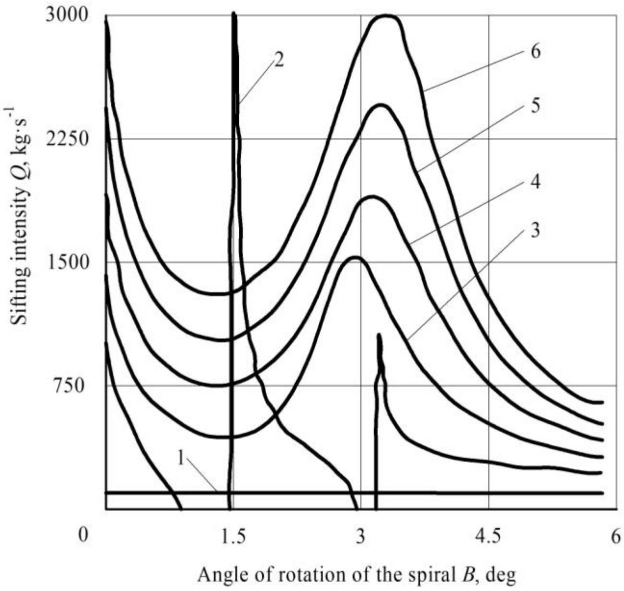

Figure 3. *Dependence of sieving intensity Q (kg·s^{-1}) from the angle of rotation of the spiral B (deg) at the angular velocity of the spiral:1 – 0 rad·s^{-1}; 2 – 10 rad·s^{-1}; 3 – 20 rad·s^{-1}; 4 – 30 rad·s^{-1}; 5 – 40 rad·s^{-1}; 6 – 50 rad·s^{-1}*

As the angular velocity of the rotational motion of the spiral increases, the intensity of separation also increases. At an angular parameter of about 3.3 rad, the intensity of separation of the soil heap increases from 0 kg·s^{-1} at angular velocity of rotational motion 0 rad·s^{-1} to 3000 kg·s^{-1} at an angular velocity equal to 50 rad·s^{-1}. With further rotation of the cleaning spirals together with the heap, the intensity of separation of soil impurities decreases. This is evidenced by the attenuating nature of the curves.

4. Conclusion

Based on the calculations and mathematical transformations performed on a PC using the developed program, an analytical expression for determining the percentage of sifted soil by the spiral separator was obtained, allowing us to study the effect of coordinate changes on the percentage of sifted soil.

Studies of soil sieving in the cleaning of the heap of root crops from impurities with a spiral-type cleaner have also been carried out. It is established that many factors influence the intensity of soil screening on the spiral separator – the initial mass, the constructive dimensions of the cleaner, the frictional properties of the surface, the angular parameters of body placement on the spiral surface and the angular speed of the spiral roller rotational motion, and the intensity of these design parameters has been studied.

A graphical dependence of soil screening intensity Q (kg·s^{-1}) on the cleaning spiral rotation angle B (deg) at angular velocity of spiral rotation from 0 to 50 rad·s^{-1} is plotted. The obtained graphical dependences indicate that in the second quadrant (on the rise of the mass on the surface of the spiral separator) the intensity of separation decreases. On the contrary, the growth of separation is investigated at lowering the ground mass.

As the angular velocity of the spiral rotational motion increases, the intensity of separation also increases. At an angular parameter of about 3.3 rad, the separation intensity increases from 0 kg·s^{-1} at angular velocity 0 rad·s^{-1} to 3000 kg·s^{-1} at angular velocity 50 rad·s^{-1}. When turning the spiral together with the heap, the intensity of separation decreases. This is evidenced by the attenuating nature of the curves.

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A methodical approach to the evaluation of vibrations of passengers of electric bus 6k2 in the task of selecting a general layout and suspension

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Abstract: *An improved methodological approach to assessing the vibration levels of passengers of a mobile car during its virtual tests on mathematical models in the design problem of choosing the parameters of the general layout and suspension of electric bus 6K2 is considered. When considering human vibrations in a machine, it is advisable to determine them taking into account the structure of the human body. Harmless vibration levels for different parts of the body are significantly different in amplitude and frequency. Vibration levels affecting a person be determined on the basis of two-mass and four-mass models of the human body, as recomended The International Organization for Standardization ISO. A computational experiment of parametric optimization of the suspension according to the proposed approach and criteria-rules allows you to find the required rational suspension parameters of the machine. The following considerations allow to carry out structural optimization of the layout of the passenger compartment of the electric bus, considering the effect of occupancy of the passenger compartment and schemes for random placement of passengers across the passenger compartment.*
KEYWORDS: *ELECTRIC BUS, CAR VIBRATION, CAR SUSPENSION, MODELS OF THE HUMAN BODY.*

Introduction

The electric bus is a complex multidimensional oscillatory dynamic system. With a steady average speed, the disturbing effects on its wheels from the microprofile of the road are described by random stationary functions. These effects, as you know, lead to the occurrence of random stationary low-frequency vibrations of the frame of the car, the driver and passengers in the seats, as well as people standing on the floor of the passenger compartment. High levels of fluctuations adversely affect human health, so their maximum permissible values are limited by law.

When developing a new electric bus and suspension of its wheels, it is necessary at the stage of choosing the parameters of the general layout, the scheme and the parameters of the suspension to make sure that the sanitary norms of vibration of a person in the car are ensured. The task is complicated due to the need to ensure a completely low floor level, kneeling mode, minimum roll and pitch with the necessary smoothness of the modern electric bus with large passenger capacity or large, for example, two-story, with a significant role of the wind load, especially acting at large angles to the direction of movement and on slopes of motion surfaces.

Given the layout of the passenger compartment, the number and placement of passengers, the load distribution on the wheels of the car changes, which changes the picture of the spatial vibrations of people in the car. In addition, the nature of the effect of fluctuations on a person on a seat and standing on the floor of the cabin varies significantly. Therefore, it is always necessary to make improvements to standard methods for studying the levels of fluctuations of people in a car.

Material and methods

The design scheme of the dynamic system of the electric bus 6K2 can be presented in the following form.

a)

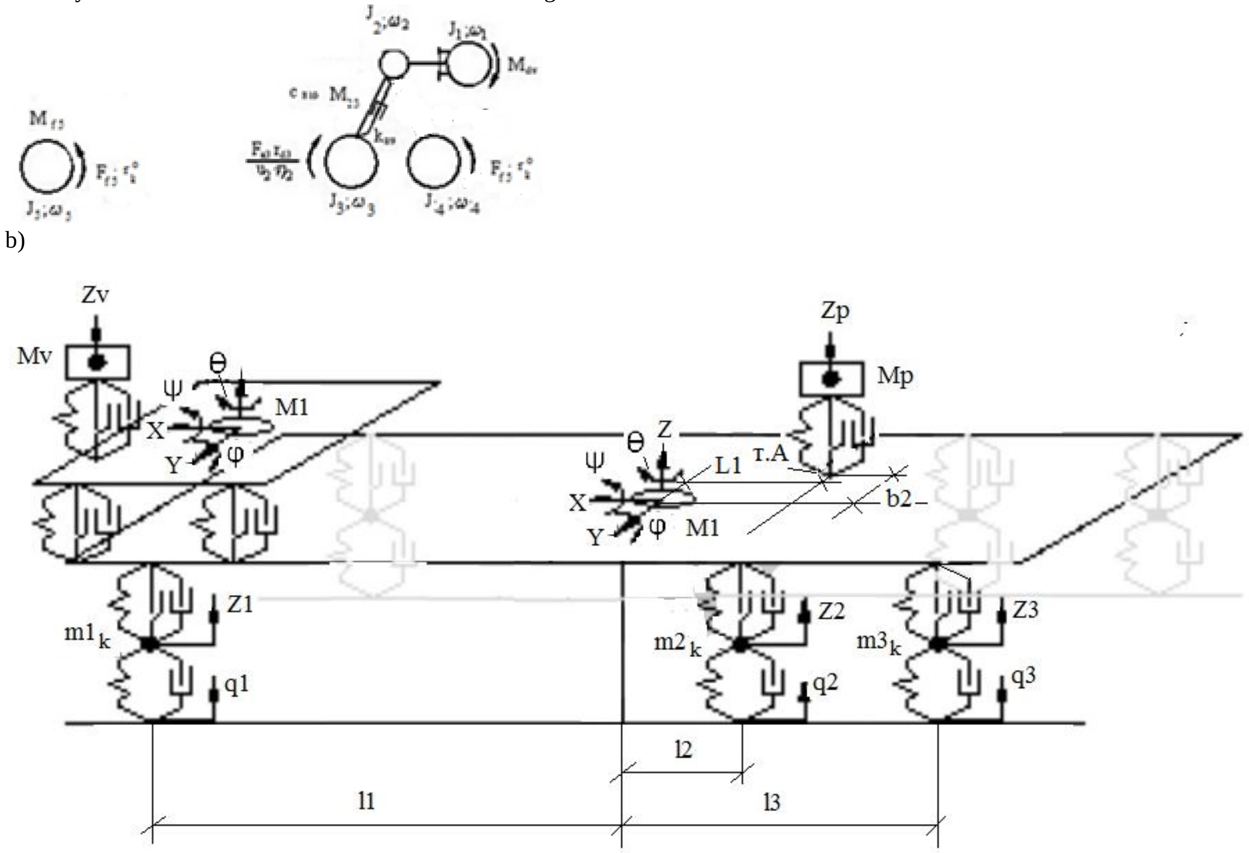

Fig. 1. *Design diagram of the electric bus 6K2: a) dynamic torsion subsystem of the wheel drive, b) the spatial dynamic oscillation system*

In Figure 1, the designations *Mv*, *Zv* correspond to the sprung mass and vertical movement of the machine and the driver sitting on the sprung seat cushion, and *Mp*, *Zp* - the same for a standing passenger in the cabin. In particular, when considering human vibrations in a machine, according to the ISO, it is advisable to determine them taking into account the structure of the human body, since for different parts of the body harmless vibration levels are significantly different in amplitude and frequency.

The developed calculation dynamic system of the electric bus with the wheel formula 6K2 (Figure 1) consists of inertial masses interacting with each other by means of elastic and dissipative elements that simulate the physical properties of the body and seat suspension mechanisms. Figure 1a shows the dynamic torsion subsystem of the wheel drive from a traction electric motor as part of the balancing wheel cart with stearing wheels of the rear axle of the electric bus, and Fig.1b shows the spatial dynamic oscillation system of the 6K2 electric bus for studying the low-frequency vibrations of the mentioned masses in the longitudinal and transverse vertical planes of interest to us.

The structure of the electrical equipment of a modern electric bus, as follows from an information analysis of well-known technical solutions, includes such basic elements as: 1) an energy storage device of battery or capacitor type; 2) charging port or charger; 3) a control device for the charge and discharge of the electron storage device; 4) automatic remote switch and power switching unit; 5) traction inverter; 6) the main controller; 7) traction motor or traction electric motors of motor-wheels; 8) CAN-bus communication elements of the electric drive control system; 9) voltage converters, as well as other elements of the electrical system.

The mathematical description of the motion of the masses *M* and m_{il} of the calculated dynamic system is performed in accordance with the methodological recommendations set forth in [Xie, 2001; Nawaysehand and Griffin, 2010]. The phase coordinates of the model are shown in Figure 1. The interaction of the inertial masses of wheels equipped with pneumatic tires with the road and the sprung masses of the dynamic system of the electric bus was modeled taking into account their elastic and dissipative characteristics.

$$\begin{aligned}
&M\ddot{z} + \sum_{l=1}^{2}\sum_{i=1}^{3}\sum_{j=1}^{3} P_{jil} = 0,\\
&I_y\ddot{\phi} + \sum_{l=1}^{2}\sum_{i=1}^{3}\sum_{j=1}^{3} l_{il}P_{jil} = 0,\\
&I_x\ddot{\psi} + \sum_{l=1}^{2}\sum_{i=1}^{3}\sum_{j=1}^{3} b_{il}P_{jil} = 0,\\
&I_z\ddot{\theta} + \sum_{l=1}^{2}\sum_{i=1}^{3}\sum_{j=6}^{7} l_{il}P_{jil} = 0,\\
&m_{il}\ddot{z}_{il} - (P_{1il} + P_{2il} + P_{3il}) + P_{4il} + P_{5il} = 0,\\
&l = 1,2;\ \ i = \overline{1\ 3};\ \ j = 1.2.3
\end{aligned} \tag{1}$$

with initial conditions for t> = t_0:
$x|_{t=t0} = x_0$, $\dot{x}|_{t=t0} = \dot{x}_0$, $z|_{t=t0} = z_0$, $\dot{z}|_{t=t0} = \dot{z}_0$, $\varphi|_{t=t0} = \varphi_0$, $\dot{\varphi}|_{t=t0} = \dot{\varphi}_0$, $\psi|_{t=t0} = \psi_0$, $\dot{\psi}|_{t=t0} = \dot{\psi}_0$, $\Theta|_{t=t0} = \Theta_0$, $\dot{\Theta}|_{t=t0} = \dot{\Theta}_0$, $z_{il}|_{t=t0} = z_{il0}$, $\dot{z}_{il}|_{t=t0} = \dot{z}_{il0}$,
where M is the sprung mass of the electric bus; mil is the unsprung mass of the il-th wheel support; Ix, Iy, Iz - moments of inertia of the sprung mass relative to the axis of pitch, roll and yaw when changing Euler angles: φ, ψ, Θ; i is the serial number of the wheel support on board, i = 1, 2, 3; j is the conditional index of the elastic-dissipative elements in the electric bus model, j = 1 is the elastic suspension element, j = 2 - shock absorber, j = 3 - element "dry friction", j = 4 - element "elasticity of the tire in the normal direction", j = 5 - element "energy dissipation in the tire during vertical deformation", j = 6 - elastic resistance rotation of the electric bus platform when yawing along the angle Θ, j = 7 - energy dissipation when yawing the electric bus platform along the angle пo; l is the conditional index of the number of the side of the electric bus, l = 1, 2; Pjil - non-linear characteristic with a variable value of stiffness of the restoring force of the conditional element il of the suspension in the model; P_{4il}, P_{5il} - respectively, restoring the elastic and dissipative normal forces of the ith bus in the electric bus model; lil is the horizontal distance along the X axis from the center of mass of the electric bus to the axis of the il-th wheel; bil is the horizontal distance along the Y axis from the center of mass of the electric bus to the axis of the elastic and dissipative suspension elements of the il wheel.

To calculate the forces in the equations of system (1), the relative displacements and their velocities in the elements of each suspension are determined by the following expressions:
Δ_il = z + lilφ + bilψ-zil, (Δ_il)˙= z˙ + lilφ˙ + bilψ˙-z˙il. Similarly, for elastic-dissipative forces in the tire of the ith wheel for j = 4, 5, the relative displacements and their velocities are equal: δil = zil-qil, δ˙il = z˙il-q˙il. The above expressions are the arguments of the corresponding forces in the system of equations (1), and these characteristics for suspensions and buses of the electric bus are most often non-linear, therefore, the expressions for them are usually approximated by a polynomial of the second and higher degrees with respect to the arguments.

This model allows you to simulate the vibrations of the frame and floor of the cabin of the electric bus at the location of standing passengers, or the seat cushion at the location of the driver. As applied to a three-axle wheeled vehicle, a detailed mathematical description of its vibrations in the longitudinal-vertical plane when driving along roughnesses of a random stationary road for studying smoothness was developed by the authors of this article in [Silaev, 1971; Wael Abbas et al., 2010; Szczepaniak and Kromuslki, 2011], therefore, a detailed mathematical description is not given here.

The micro profile of the road surface was described by an exponential-cosine correlation function. Such functions were determined by the results of: 1) either field measurements using the theodolite of the ordinates of selected characteristic sections of city roads with the subsequent removal of the expectation trend; 2) either ordinates were taken from the test road tables recommended by the standards; 3) either, according to the correlation functions of the roads known from the scientific literature, the ordinates of the height of the microprofile were found according to the algorithm of Furunzhieva, while you can use the most general expression of the correlation function of the form:

$$Rq(\tau) = A1 * \sigma 2e - \alpha 1e * |\tau| + \ A2 * \sigma 2e - \alpha 2e * |\tau| * cos\beta e * \tau$$

where A1 and A2 are the weight coefficients of the correlation function formula for a specific random road, with A1 + A2 = 1; σ - root-mean-square deviation of the height - coordinates of road irregularities: α1e, α2e - parameters in terms of exponential powers, reflecting the rate of correlation attenuation of the relationship between the heights of the road micro-profile; βe is the parameter of the cosine harmonic component of the microroughness heights of the road.

The time discretization step in determining statistical estimates of the probabilistic characteristics of oscillations is determined by the Kotelnikov-Shannon theorem and is taken equal to 0.025 s from the experience of such studies. The parameters of low-frequency oscillation processes are determined in the frequency range in which the sanitary standards for low-frequency vibration velocities and acceleration in the octave and one-third octave frequency bands are regulated, and in which the values of the natural frequencies of vibrations of the dynamic oscillatory system of the electric bus.

The processing of the measured ordinates of the microprofiles of the roads along which the electric buses travel, as well as the values of displacements, speeds and accelerations of low-frequency oscillations, measured at a selected point of the machine during movement, in order to obtain their statistical characteristics, is carried out according to the relationships that are identical in structure, for the microprofile - as a function of length s path, and for oscillations - as a function of time *t*:

mathematical expectation mx of the written data x_i: $m_x = \sum_1^N xi/_N$,
where N number of data items; standard deviation, σ_x data implementation:

$\sigma_x = \sqrt{\frac{1}{N}\left(\sum_1^N x_i^2 - N \cdot m_x^2\right)}$;

the values of the correlation coefficients of the autocovariance function for the microprofile and for oscillations at sampling times, respectively, $\Delta x \; or \; \Delta t$:

$$R_x(j) = \frac{1}{N-j} \cdot \sum_{i=1}^{N-j} (x_i - m_x) \cdot (x_{i+j} - m_x) \, , j = 0,1,2,3,..; \; \tau = j \cdot \Delta t,$$

where $R_x(j)$ - j- th correlation coefficient corresponding to the correlation interval τ *в (м) or в (с)*; spectral density of random processes of micro-profile heights and values of low-frequency oscillations as a function of an infinite set of frequencies ω random process $S_x(\omega) = 2 \cdot \int_0^\infty R_x(\tau) \cdot \cos(\omega \cdot \tau) \cdot K_T(\tau) \cdot d\tau,$

where $K_T(\tau)$ – Tukey weighted time correlation window

$$K_T(\tau) = \left[\begin{matrix} 0{,}5 \cdot \left(1 + \cos\frac{\pi \cdot \tau}{T_0}\right), |\tau| \le T_0. \\ 0, |\tau| \le T_0. \end{matrix}\right]$$

The Tukey time window in spectral analysis provides for obtaining estimates of the spectral densities of the road micro-profile and the spectral density of low-frequency oscillation meters corresponding to the physical nature of the studied processes, with a practically expedient limitation of the maximum value of the correlation time interval T_0, if the process record length is $T = \Delta t \cdot (N-1)$ much larger than T_0, for example, for the spectral densities of processes depending on the speed of the machine. When analyzing the smooth running of cars, the relative width of the Tukey window T_0 / T is usually taken to be 12. Moreover, the upper infinite limit of integration when calculating the integral in the spectral density formula is replaced by a finite value of T_0, then the integral is simply calculated by one of the numerical methods for a certain countable set of frequencies ω, for example, according to the Simpson formula, taking the step h of dividing the integration interval equal to the sampling step of the original time series *Δt*. Using the obtained values, we build graphs spectral densities of the input micro-profile depending on the speed of the machine and the graphs of the parameters of random oscillations.

As is known from the spectral theory of suspension of wheeled vehicles [Silaev, 1971], the correlation function is the original, and the spectral density is the Fourier image, then.

$$R_X(\tau) = \frac{1}{\pi}\int_o^\infty S_X(\omega) \cdot cos(\omega\tau) d\omega \cdot$$

and the value of R_x (τ = 0) is equal to the variance of a stationary random process, that is. $D_x = \sigma_x^2 = R_x(0) = \frac{1}{\pi}\int_o^\infty S_x(\omega) \cdot d\omega$ ·

The frequency range is divided into octave or one-third-octave intervals, in which the rms values of the vibration parameters on the driver's seat, on sitting and standing passengers, at a selected point of the machine frame are obtained by integration, which, depending on the purpose of the study, are compared with the permissible standard values, for example, by GOST 12.2.019-91, or according to the guidelines of the European Union, or assess the influence of the design parameter of the suspension or the parameter of the general arrangement on the smoothness of the machine.

Calculations and full-scale tests of the smooth running of high-speed machines, which include electric buses, as well as an analysis of known guidelines on the topic, allow us to consider it justified to limit the upper considered value of the frequency range to 32 Hz. This value is used when integrating over the area in octave frequency bands under the spectral density curve to determine the variances in the allocated octaves of frequencies that are equal to the corresponding area of the band divided by the number π.

The speed of the electric bus significantly affects the nature of the oscillations and, during simulation, discretely changes from 10 to 60 km/h in order to identify possible zones of manifestation of statistical resonances, which are characterized by a significant increase in the amplitudes and accelerations of oscillations. The estimated oscillation parameters are determined using the calculated correlation function, which allows calculating the ordinates of the spectral density as a function of the oscillation frequency, and then, integrating the spectral density graph in the frequency bands, determine the rms deviations of vibration accelerations, or vibration velocities, or vibration displacements of interest, since on the human body, with with an increase in frequency, different vibration parameters have the main adverse effect.

Spectral densities, as described earlier, are calculated based on the ordinates of the correlation functions, which are smoothed using the Tukey correlation window. In a machine study of the vibrations of an electric bus, graphs of the dependences of the above estimates of vibrations of the floor of the passenger compartment of an electric bus at characteristic points should be obtained depending on the coefficients of the stiffness of the elastic elements and the coefficients of resistance of the dissipative elements of the suspension of the electric bus and passenger seats, as well as on the mass-geometric parameters of the general layout of the machine.Spectral densities are calculated based on the ordinates of the correlation functions, which are smoothed using the Tukey correlation window. In a machine study of the vibrations of an electric bus, dependency graphs of the mentioned estimates of the floor vibrations of the interior of the electric bus at characteristic points depending on the stiffness coefficients of the elastic elements and the resistance coefficients of the dissipative suspension elements of the electric bus and passenger seats should be obtained.

The described process of studying the vibrations of a wheeled vehicle has been methodologically well worked out by scientists and designers of Belarusian electric buses. However, the increased requirements for the smoothness of the machines of new layout schemes and wheel formulas, comfort and safety for human health, taking into account the structure of his body, complicate the task of the study.

Thus, at the second stage of the study, mathematical models are used, developed on the basis of biomechanical calculation models of a person in a car in a sitting or standing position, similar to those given. Moreover, the input action is the corresponding values determined as a result of the first stage of virtual research, for example, the current ordinates of movement of either the seat frame or the floor point of the passenger compartment, above which the standing passenger is placed.

Further, as a result of modeling on a biomechanical model, the spectral densities of vibration velocities or accelerations of low-frequency vibrations of each of the structural parts of the human body are also determined, their root-mean-square values in the third-octave or octave frequency bands of the vibration spectrum are calculated and compared with acceptable levels according to medical standards, which do not cause a negative impact on the health of the person in this machine.

Results

To take into account the structure of the human body in this study, it is advisable to apply the method of sequential consideration of related local models. The essence of the reception is to determine, at the first stage, on a mathematical model of the characteristics of vehicle vibrations in the process of simulation.

As a result, the values of the ordinates, velocities, and accelerations of oscillations at any point of the sprung mass of the carrier system of the machine are determined, knowing the values of the listed quantities in its center of mass, in accordance with the methodological approach [Silaev, 1972] described below with reference to the problem under consideration. And then on a separate mathematical model of the human body, we study the effect of the oscillations of the floor of the passenger compartment at the passenger’s standing point on the parameters of the oscillations of body parts and compare them with the medical restrictions for this part of the body.

The natural vibration frequencies of a standing passenger's body for a two-mass dynamic model (Figure 2b) and the amplitude-phase frequency characteristics of displacements and accelerations of body masses expressed in terms of model parameters are determined using well-known expressions [Silaev 1972; Tayanovsky, Atamanov, Tanas, 2013].

a) *b)*

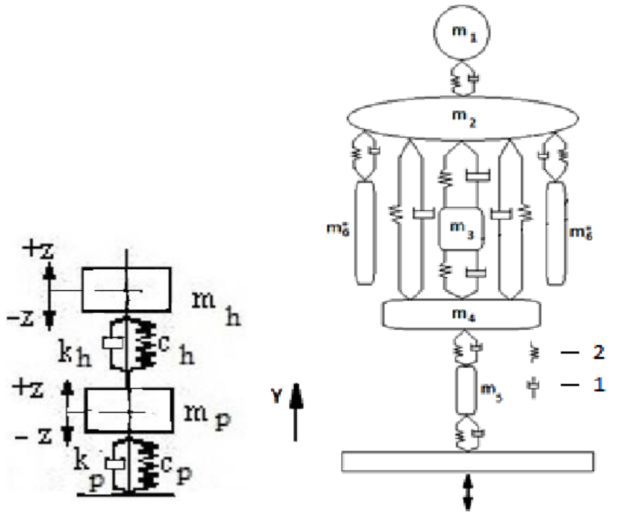

Figure 2. *Dynamic models of a standing passenger with a different number of masses, perceiving vertical vibrations from the floor of the electric bus: a) six-mass model of the body of a passenger, b) 2-mass model, m_1 – head, m_2 – upper torso, m_3 – lower torso, $_{m4}$ – thighs (pelvic), 1 - model of flexible body parts, 2 - model of dissipartive body parts.*

As is known from the spectral analysis of vibrations [Jenkins 1971], when an object with a known function of spectral density Sin (ω) is exposed to an object with the transfer function Φ (p) the spectral density of oscillations at the exit from the object is $S_{Zoutput}(\omega)= S_{Zinput}(\omega)\times|\Phi(i\omega)|^2$,
and the dispersion of accelerations are determined, for the problem under consideration, from the expression

$$.\sigma_z^2 = \frac{1}{\pi}\times\int_0^{+\infty} Sz_{output}\,(\omega)d\omega$$

In the above mathematical description of the electric bus oscillations (1), accelerations of the center of mass of the machine were considered. The acceleration of points located at a certain distance from the center of mass, due to the presence of longitudinal-angular, transverse-angular oscillations, often exceeds the accelerations of the center of mass by several times. For example, take point A on the floor of the passenger compartment of an electric bus (see Figure 1), located from the center of mass of the machine at a distance L1 from the transverse and at a distance b2 from the longitudinal axes passing through the center of mass of the machine. From geometric considerations and the principle of superposition of oscillations, the following record is valid

$$Z_A(t) = z(t) + \varphi(t)l_1 + \psi(t)b_2, \quad (2)$$

where
Z_A (t) - vertical movement of the floor of the cabin at point A;
z (t) - is the vertical displacement of the center of mass of the electric bus;
φ (t) and ψ (t) - are the longitudinally-angular and transverse-angular oscillations of the floor of the passenger compartment of the electric bus, respectively.

It should be noted that in expression (2) the quantities φ (t) and ψ (t) are taken with a plus sign, since we need to determine the maximum values of the displacement and acceleration of point A. We pass from the originals of the listed quantities to their operator images according to Laplace, then after the functional transformation, equation (2) is written as follows:

$$Z_A(p) = z(p) + \varphi(p)l_1 + \psi(p)b_2,$$

where p is the direct Laplace transform operator. Using the techniques of the theory of automatic control, after replacing p by iω, we obtain the frequency response of the movements of point A through the frequency characteristics of three simple oscillations of the core of the electric bus in the center of mass:

$$Z_A(i\omega) = z(i\omega) + \varphi(i\omega)l_1 + \psi(i\omega)b_2, \quad (3)$$

where i - is the imaginary unit; ω is the oscillation frequency.
Equation (3) reflects the dependence of the frequency characteristic of the movement of point A on the frequency characteristics of the longitudinal-angular and vertical linear vibrations of the floor of the passenger compartment in the center of mass of the electric bus. Further, according to the frequency response of the displacement of point A and the spectral density of the impact $S_{вх}(\omega)$ at the floor point of the passenger compartment, corresponding to the center of mass of the backbone of the electric bus, the energy spectrum of displacements during the oscillations of point A is determined:

$$S_{zA}(\omega) = |\,z(i\omega) + \varphi(i\omega)l_1 + \psi(i\omega)b_2|S_{вх}(\omega). \quad (4)$$

Taking the second time derivative of the value Z_A (t) in expression (2), we obtain an equation that determines the vertical acceleration of point A:

$$\ddot{Z}_A(i\omega) = \ddot{z}(t) + \ddot{\varphi}(i\omega)l_1 + \ddot{\psi}(t)b_2. \quad (5)$$

A single differentiation in the material region corresponds to multiplication by iω in the complex region; therefore, the frequency response of the vertical acceleration of point A of the body, obtained from expression (3), will take the form [Silaev. 1972]:

$$\ddot{Z}_A(i\omega) = -\omega^2\,[z(i\omega) + \varphi(i\omega)l_1 + \psi(i\omega)b_2] \quad (6)$$

Equation (5) allows you to determine the frequency response of the acceleration point A of the body from the frequency characteristics of vertical, longitudinal-angular oscillations and transverse-angular oscillations in vertical planes. The energy spectrum of the vertical accelerations of point A of the body is the spectral density of the accelerations of point A:

$$S_{\ddot{z}A}(\omega) = \omega^4|\,z(i\omega) + \varphi(i\omega)l_1 + \psi(i\omega)b_2|^2 \times S_{input}\,(\omega). \quad (7)$$

If the spectral displacement density is determined, then in this case, to determine the spectral density of acceleration using equation (7). To obtain the spectral acceleration density, it is enough for each value of ω to multiply the magnitude of the spectral displacement density by ω^4. If the energy spectrum of displacement has not been determined, then to determine the energy spectrum of acceleration should use equation (6). Dispersion of vertical acceleration of point A of the body:

$$\sigma_{\ddot{z}A}^2 = \frac{1}{\pi}\int_0^{\infty} S_{\ddot{z}A}(\omega)\,d\omega. \quad (8)$$

As already mentioned, this integral is determined by the area enclosed between the curve of the spectral density of acceleration and the coordinate axis of the frequencies. And the rms accelerations in the octave frequency bands, respectively, are determined by the area under the same curve and the abscissa axis, between the boundary frequencies of a specific octave band.

Discussion

The International Organization for Standardization ISO recommends that a more detailed picture of vibration levels affecting a person be determined on the basis of two-mass and four-mass models of the human body, as medical advances have shown that different values of vibration levels and frequencies are dangerous for different parts of the body. For example, in the well-known multi-mass models [Wael Abbas et al. 2010, Baglaychuk 2014, Kromulski et al. 2016], a human body seated on a seat can be represented by four separate mass segments connected by five or four sets of springs and dampers (Figure 3).

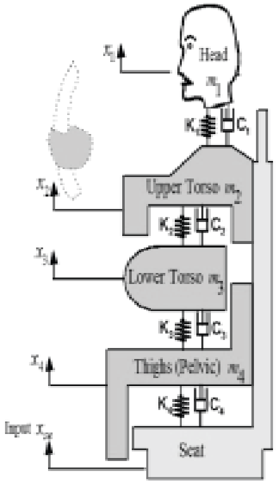

Figure 3.*Topological dynamic 4-mass model of the body of a seated person for studies of its vibrations while in the car*.

These four masses in Figure 3 represent the following body segments: head and neck, upper torso, lower torso, hips and pelvis. Figure 2a shows a six-mass model of the body of a passenger standing on the floor of the cabin of the electric bus, and in position b) of the figure, it is simplified to a 2-mass model, which is necessary to assess the levels of vibration parameters of parts of the body of a standing passenger in the cabin of the electric bus.

Conclusion

Conclusion is drawn on the acceptability of the machine parameters that determine such levels of oscillation. All studies are carried out for various speeds provided by the propulsion-transmission-propulsion unit of the electric bus (see Figure 1a).

`A computational experiment of parametric optimization of the suspension according to the proposed approach and criteria-rules allows you to find the required rational suspension parameters of the machine. The described approach using a set of local models is also convenient because it is possible to apply as input the effects determined by the results of field tests on human models, since measurements of low-frequency oscillation parameters on the human body and internal organs are still difficult in wide practice.

In addition, compiling, debugging software applications and conducting virtual simulation in this case is much simpler than on one common complex model. The expanded variational capabilities of the stated general structure of the study also make it possible to carry out structural optimization of the layout of the passenger compartment of the electric bus, considering the effect of occupancy of the passenger compartment and schemes for random placement of passengers across the passenger compartment, on the load on the load-bearing skeleton, undercarriage system and vibration levels of the skeleton and passengers.

The presented revised methodological provisions allow us to perform a theoretical calculation that limits the ability to operate the electric bus, suspension parameters and driving modes according to the criteria of ride, select rational parameters of both the suspension and the general layout, and the layout of the cabin.

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ИЗСЛЕДВАНЕ ГРАПАВОСТТА ПРИ СРАБОТВАНЕ И ИЗНОСВАНЕ НА ПРЕВАНТИВНИ И ВЪЗСТАНОВИТЕЛНИ ВИБРОДЪГОВИ И ЕЛЕКТРОХИМИЧНИ ПОКРИТИЯ ПРИ ТЕЧНО ТРИЕНЕ

ROUGHNESS AND WEAR INVESTIGATION OF PREVENTIVE AND RESTORATIVE VIBRO-ARC AND ELECTROCHEMICAL COATINGS IN LIQUID FRICTION DURING INTERACTION

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Abstract: *The article examines the change in the roughness of preventive and restorative coatings for the restoration of worn parts in liquid friction. The change in the roughness of the reference and restored with iron, phosphate and welded DUR500 coating rollers) is equidistant, as the magnitude of the equilibrium roughness depends on the initial roughness of the friction surfaces. The lower roughness of the desired, welded with DUR500 and electrochemical lead alloy EO92 surface of the roller Ra = 0.32 μm from the roughness of the reference and phosphated roller Ra = 0.38 μm leads to less wear during operation and established wear. The higher equilibrium roughness of the pair with a desired roll Ra = 1.55 μm creates better conditions for the formation and preservation of the oil layer, less wear during operation and established wear and greater wear resistance at the same microhardness of work surfaces ..*

Keywords: *recovery, friction, preventive and restorative coatings*

1. Въведение

Сработването е неизбежен период от работата на триещите се двойки [1, 2, 12]. При триенето между плъзгащите се повърхности протича процес на сработване, който се съпровожда с промяната на микрогеометрията на триещите се повърхности. В резултат на това неравностите на повърхностите изменят своята форма, размер и направление. В отличие от първоначалните неравности след сработването те са насочени по направление на плъзгането на триещите се повърхности [12, 17].

Продължително време сработването беше свързано изключително с изменение на геометрията на повърхностите в границите на износването, не превишаващо височината на началната грапавост на тези повърхности. Считаше се, че процеса на повишаване на носещата способност, практически съвпада с процеса на повишаване на опорната повърхност при сближаване на триещите се повърхности, като износването при сработването и установеното износване се състои само в постепенно изтриване на микронеравностите от върха до основата им.

Микрогеометрията на повърхностите след сработване се отличава, като правило със случаен характер на височината на профила. В резултат на сработването грапавостта на работните повърхности достига някаква равновесна стойност характерна за дадени условия на триене и износване. Също така се променят и физико-механичните свойства на повърхностните слоеве, вследствие на пластическата деформация. Грапавостта на триещите се при плъзгане повърхности се изменя не само в резултат на деформациите, но и в резултат от износването най-вече на върховете на микронеравностите. [4, 5, 8, 9].

Целта на работата е експериментално установяване изменението на грапавостта на двоици от различни материали с нанесени превантивни и възстановителни вибродъгови и електрохимични покрития при триене на плъзгане в течна среда.

Обект на изследване е динамиката на изменение на грапавостта на ролката и сектора в процеса на сработване на двоици с нанесени превантивни и възстановителни вибродъгови и електрохимични покрития работещи на триене при плъзгане в течна среда от масло SAE 30 [15].

2. Изложение

Методиката за изследване е разработена съобразно съвременните изискванията за триене и износване при течно триене, съответстващи на експлоатационните условия и възможностите на техническите средства за тези изследвания [12, 13, 15].

Моделът за изследване съгласно кибернетичните принципи се изразява с основните входни фактори и изходни параметри на обекта на изследване.

За входни фактори на модела за изследване процеса на сработване и износване при течно триене на плъзгане на електрохимични покрития са приети: състава и свойствата на материала на възстановителните електрохимични покрития; състава и свойствата на материала на превантивните електрохимични покрития от автотракторната и земеделска техника [13].

За физическия модел на триещото се съединение "вал-лагер" е приета двоицата "ролка-сектор" със съответните параметри на физическо и геометрично подобие. Параметрите на образците за изпитване са избрани със структурни характеристики, определени въз основа на статистическо изследване на подлежащите на възстановяване детайли от автотракторната и земеделска техника [3, 4, 5, 6, 8, 16].

На сравнително изследване бяха подложени следните материала на триещата се повърхност на ролката стомана 45 закалена, стомана 45 пожелезена, стомана 45 фосфатирана и стомана 45 наварена вибродъгово в газова смес с DUR500 [11, 17]. Възстановените образци (ролки) се изработваха от Ст45 с нанесено върху тях желязно покритие, стомана 45 вибродъгово наварена с DUR500 в газова смес от аргон и въглероден двуокис и превантивно покритие от стомана 45 с конверсионно фосфатно покритие.

Пожелезяването е извършено в хлориден електролит при концентрация на железния двухлорид $FeCl_2.H_2O$ 300 g/l, подкиселен със солна киселина HCl до стойност на водородният показател 0,9 pH. Режимът на напластяване е следния: температура на електролита 60 ^oC; начална плътност на тока Dк=0,3-0,5 A/dm^2 в продължение на 2-3 min; плътност на тока по време на напластяването Dк=1,35-1,37 A/dm^2; време на напластяване 12 h; твърдост на покритието HV 5500 MPa.

Възстановените ролки са изработени от Ст-45 наварена с електроден тел DUR-500 с диаметър 1,6 mm в газова смес от аргон и въглероден двуокис при състав от 60% Ar и 40% CO2 който осигурява висока твърдост и износоустойчивост на наварената повърхност [3, 14]. Навяряването е извършено при режим: Работно електрическо напрежение-20 V, големина на електрическия ток-150 A, скорост на наваряване 1,26 m/min, скорост на подаване на електродния тел 2,3 m/min,стъпка на наваряване 3 mm/tr, излаз на електродния тел 15 mm, разход на защитен газ 15 l/min на уредба с без инерционен осев вибродъгов апарат АВН 60 с честота на вибрациите 46,7 Hz.

За приготвяне на разтвора за конверсионното фосфатно покритие се използваше дестилирана вода. Обработката протича във вана, оборудвана с нагревател и вентилация при следния състав на електролита и режима за нанасяне на фосфатното покритие. Електролитът, с който се провежда изследването е в състав: H_3PO_4 с концентрация 70-90 g/l, $NaNO_3$ с концентрация 13-19 g/l и ZnO с концентрация 1,0-2,0 g/l. Температурата, при която се осъществява процеса е стайна 20-25ºC. При обработка в стационарна вана продължителността на процеса е 35-50 min.

Еталонните и фосфатирани образци се обработваха термично, като се закаляваха при нагряване с ТВЧ и опускаха до твърдост $55^{\pm 2}$ HRC ($HV_5 = 6100^{\pm 400}$ MPa), след което се нанасяше конверсионното фосфатно покритие. Еталонната, фосфатираната и пожелезена ролки се обработваха механично, като се шлифоваха на окончателен размер по специална методика, след изработването от тях на ролки за изпитване. Ролките имаха диаметър на триещата се повърхност $50^{+0,02}$ mm, не съосност и неперпендикулярност не повече от 0,01 mm, ширина $12^{+0,05}$ mm, дебелина на желязното.

Наварените ролки се обработваха термично и механично, като се закаляваха с ТВЧ на твърдост 55 HRC и шлифоваха на окончателен размер. Ролките след обработване имаха диаметър на триещата се повърхност $50^{+0,02}$ mm с грапавост Ra = 0,28-0,32 μm, ширина $12^{+0,05}$ mm, дебелина на навареното покритие 0,5 mm по радиуса и маса от 160-170 g.

Секторите са биметални със стоманена основа и нанесен върху нея антифрикционен слой от БО-30 с твърдост HV5 = $490^{\pm 50}$ MPa и дебелина 0,1-0,5 mm по радиуса. Върху част от секторите е нанесена електрохимична антифрикционна сплав ЕО-92 на основата на оловото от силикофлуороводороден електролит, който е със състав [5]:

Оловен силикофлуорид($PbSiF_6$) 100-150 g/1

Калаен силикофлуорид($SnSiF_6$) 2 0-30 g/1

Меден силикофлуорид(CuSi|F6) 5-15 g/1

Силикофлуороводородна киселина (H_2SiF_6) до pH 0,5

Отлагането на електрохимичното покритие се извършва с плътност на постоянния ток Dk = 2A/dm2 при температура 18-25°C.

Еталонните и възстановените сектори за триене с ролките се изрязваха с централен ъгъл 46° от предварително подготвените стоманени пръстени с нанесен върху нея антифрикционен слой от БО-30 с твърдост $HV_5 = 490^{\pm 50}$ MPa и дебелина 0,1-0,5 mm по радиуса и ЕО-92 с дебелина 0,15-0,25 mm по радиуса и имаха ширина $10^{+0,05}$, дължина 20 mm с триеща се повърхност от 2 cm^2 и маса 18-19 g. Външната повърхност на пръстените се шлифова до диаметър $70^{+0,1}$ mm, а вътрешната повърхност на еталонните и възстановените лагерни пръстени се престъргва до диаметър $50^{+0,06}$ mm с грапавост за секторите за БО30 Ra = 2,0-2,8 μm и грапавост за ЕО92 Ra = 0,95-1,20 μm. Хлабината на двоицата трябва да бъде 0,04-0,05 mm, (осъществява се чрез селекция) за да се получи равномерно сработване при нужния маслен клин.

За еталон беше прието сработването на двоицата стомана 45 и оловен бронз БО-30, като най-разпространените материали за плъзгащи лагери в автотракторната и земеделска техника [12]. За сравнение се използваше сработването на двоиците съставени от превантивни и възстановителни покрития за валове и лагери. Сработването и износването на еталонната и възстановените двоици се извършва в масло SEA 30.

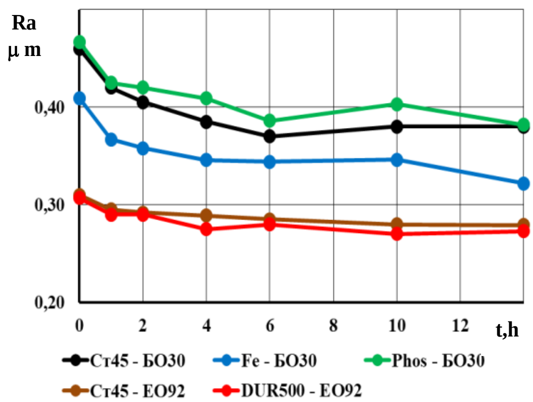
Основните изходни параметри на модела за изследване са вектора на параметрите на грапавостта. Като основен критерии за оценка на качеството на превантивните и възстановителни електрохимични покрития в процеса на сработване и износване на триещите се при плъзгане повърхности бяха приети големината на грапавостта на ролката и сектора. В процеса на изследване процеса на сработване и износване на триещите се при плъзгане повърхности са определени средната грапавост на ролката и сектора, грапавост на входа и изхода на сектора, и изменението на грапавостта по дължина на сектора [10, 11].

Изследването е проведено на машина за триене и износване СМЦ-2, усъвършенствана с различни системи и устройства за осигуряване на условия за триене с масло SAE 30 и износване близки до експлоатационните. За точно измерване на триботехническите характеристики към машината е разработена специална малко обемна водоохлаждаема камера за триене и износване в условията на течно смазване с обем от 150 ml и системи за охлаждане на камерата, поддържаща постоянна температура 40˚C, характерна за студено сработване на новоизработени и ремонтирани двигатели на автотракторната и земеделска техника, система за непрекъснато разбъркване на смазочната среда и магнитно почистване на продуктите от износването. Изпитването се извършва по схемата “ролка-сектор” при честота на въртене 540 min-1 осигуряваща относителна скорост на плъзгане 85 m/min. Натоварването на триещата се двоица се извършваше безстепенно със скорост 1 MPa/min, усилие на притискане на секторите към ролките 100 daN, което осигурява налягане 5 MPa и триботехническа характеристика PV = 425 MPa.m/min. Тези стойности са избрани в съответствие с изискванията към допустимите стойности за плъзгащи лагери.

В процеса на сработване и износване на образците се измерваха и записваха продължителността на изпитване за всеки опит, температурата на маслото, честота на въртене и сумарните обороти на ролката.

Моментът на триене на изпитваната двоица непрекъснато се измерва и записва от система с индуктивен датчик, поставен между редуктора и шпиндела на машината. За преобразуване на сигнала от индукционния датчик за момента на триене е разработена специална платка, която определя диференциала от двете намотки на датчика. Отчитането и записването на изходящия от диференциалната платка сигнал за момент на триене се извършва с мултифункционалното устройство NI-USB 6210. За преобразуването на записаните данни в N.cm е създадена блок схема, по която се отчитат и визуализират записваните данни, заложена в задвижващия софтуер NI-DAQmx и софтуерния продукт Lab View. По време на експерименталните изследвания, устройството NI-USB 6210 се свързва към USB порт на преносим компютър, а данните от записа на процеса на триене при плъзгане в реално време се съхраняват в *.xls документ и последващото им обработване се извършва с помощта на софтуерния продукт Microsoft Office Excel. Момента на триене непрекъснато се записва по време на изпитването и се визуализира на екрана на персонален компютър в цифров и в графичен вид.

Преди и след всеки опит се измерваше грапавостта на триещите се повърхности на ролката и сектора. Грапавостта беше определяна по средноаритметичното отклонение от средната линия на профила на микронеравностите (Ra, μm) с уред за измерване на грапавост “Mitutoyo” в четири сечения за ролката и пет сечения за сектора.



Фиг.1. Изменение грапавостта на ролката при различен материал на триещата се повърхност на ролката

Резултатите от изследването са представени с графични зависимости (фиг. 1 - фиг. 5), които показват динамиката на изменение на грапавостта на триещите се повърхности на ролката и сектора.

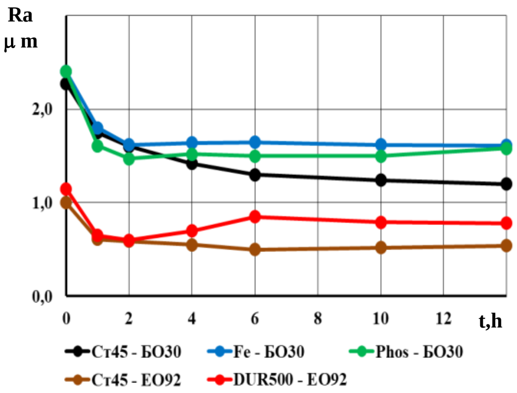
Известно е, че при сработването и износването голямо значение имат контактните взаимодействия на триещите се повърхности [22, 47]. Сработването е свързано преди всичко с изменение геометрията на триещите се повърхности в границите на износването, непревишаващо височината на началната грапавост на повърхностите.

Изменението на грапавостта на еталонната и възстановените с желязно, фосфатно и наварено DUR500 покритие ролки (фиг. 1) е еквидистантно, като големината на равновесната грапавост зависи от началната грапавост на триещите се повърхности.

В процеса на сработване и установено износване изменението на грапавостта на ролките от двоиците с електрохимична оловна сплав ЕО92 и DUR500 намаляват незначително (от 0,30-

0,32 μm до 0,27-0,29 μm) и запазва еквидистантен характер до края на изпитването (фиг.1).

В процеса на сработване и установено износване грапавостта на еталонната и възстановените с желязо и фосфатирани стоманени ролки, намалява по-значително от Ra = 0,40-0,45 μm до Ra = 0,32-0,38 μm в сравнение с другите възстановени двоици. Грапавостта на възстановената ролка намалява значително при сработването в първите два часа от Ra = 0,40 μm до Ra = 0,36 μm. Работната повърхност на ролките от възстановените с превантивни и възстановителни електрохимични покрития се сработват по-бързо, като равновесната грапавост се установява по-бързо след първите два часа на изпитването, докато еталонната ролка се сработва до шестия час. По-ниската равновесна грапавост на пожелезената, наварената с DUR500 и електрохимичната оловна сплав ЕО92 повърхност на ролката Ra = 0,32 μm от равновесната грапавост на еталонната и фосфатирана ролка Ra = 0,38 μm води до по-малко износване при сработване и установено износване (фиг. 1).



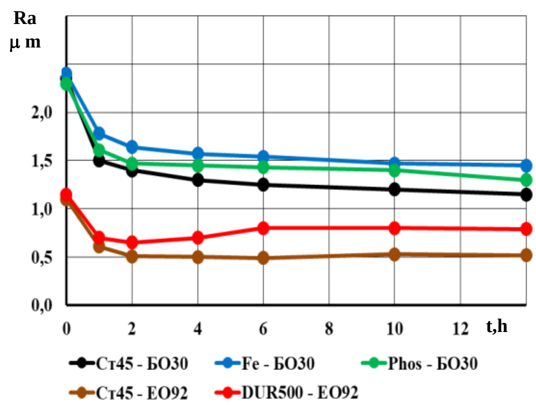
Фиг.2. Изменение грапавостта на триещата се повърхност на сектора при различен материал на повърхността на ролката

В процеса на сработване и установено износване грапавостта на секторите се променя съществено в сравнение с грапавостта на ролките (фиг. 1 и фиг. 2), поради многократно по-ниската микротвърдост на техните повърхности. Грапавостта на антифрикционния слой на сектора (фиг. 2) и за еталонната, пожелезената и фосфатирана двойки намалява почти два пъти за кратко време в процеса на сработване, от Ra = 2,35-2,45 μm до Ra = 0,80-1,55 μm.

Интензивното сработване на секторите за възстановената и с превантивно покритие двойка се извършва в първите два часа, а за еталонната продължава до шестия час. Установяването на равновесната грапавост на секторите за четирите двойки се извършва за това време, до края на изпитването грапавостта се запазва почти постоянна, това е ярко изразено при ролките с превантивно и възстановителни покрития. Активното сработване на триещите се повърхности на секторите за двоицата с ЕО92 и DUR500 протича още през първия час, като изходната технологическа грапавост бързо намалява от Ra = 1,20-2,40 μm до Ra = 0,80 μm след което настъпва равновесната грапавост на повърхностите (фиг. 2).

Равновесната грапавост на повърхността на сектора (Ra = 0,80 μm се определя от грапавостта на ролката, поради нейната значително по-голяма твърдост, но остава винаги по- голяма от равновесната грапавост на ролките, която за Ст 45 е Ra = 0,29-0,32 μm и за DUR 500 Ra = 0,27-0,31 μm. Равновесните грапавост на възстановената повърхност на сектора от двоица DUR 500-ЕО 92 и сектора от еталонната двоица Ст 45-БО 30 се изравняват при Ra = 0,80 μm, независимо от малките разлики в грапавостта на ролките. По ниската равновесна грапавост на наварената ролка съответства на по-малко износване при сработване на възстановената двоица (DUR 500 - ЕО 92).

Равновесната грапавост на сектора от двойката с пожелезеното покритие върху стоманени детайли е най-висока Ra = 1,55 μm, а тези на сектора за еталонната е по-ниско Ra = 1,20 μm. Въпреки почти еднаквата начална грапавост на антифрикционния слой за двете двоици равновесната ѝ грапавост на еталонната двойка Ra = 1,2 μm е по-ниска в сравнение с равновесната грапавост на възстановената с желязо двойка Ra =1,55 μm. По-високата равновесна грапавост на двойката с пожелезена ролка създава по-добри условия за образуване и запазване на масления слой, по-малко износване при сработване и установено износване и по-голяма износоустойчивост при една и съща микротвърдост на работните повърхности.

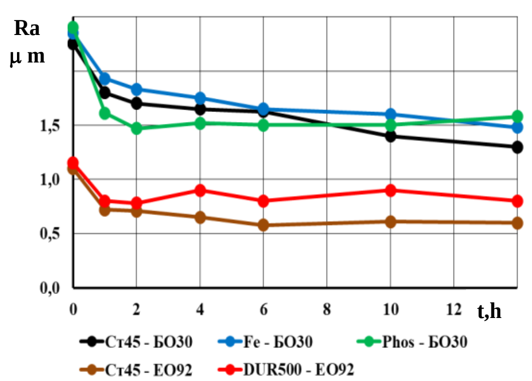


Фиг.3. Изменение грапавостта на триещата се повърхност на входа на сектора при различен материал на повърхността на ролката

Разликата между равновесната грапавост на сектора и ролката е два пъти и половина по-голяма при двойката с възстановената с пожелезяване стоманена ролка 1,23 μm отколкото при двойката с еталонна ролка 0,81 μm. По-малката разлика в равновесната грапавост на еталонната двойка, означава, че процеса на сработване и износване протича по-интензивно при нея в сравнение с пожелезената стоманена ролка.

Равновесната грапавост на триещата се повърхност на входа на сектора (фиг. 3) се установява по-бързо и на по-ниско равнище при еталонната двойка Ra = 0,35 μm, която стойност е 7 пъти по-малка от началната грапавост Ra = 2,50 μm, като равновесната грапавост се установява след втория час, както е при триещата се повърхност на ролката от тази двойка. При възстановената двойка това намаление е близо 2,5 пъти по-малко, а равновесната грапавост на повърхностите на входа на сектора е два пъти по-голяма от тази на еталонната двойка (фиг. 3).

Сработването на триещите се повърхности на входа на сектора за ЕО92 има различен характер и достига различни стойности на равновесната грапавост различна от еталонната двоица (фиг.3). Двата антифрикционни слоя на секторите (БО-ЗО и ЕО-92) се сработват с ролките много бързо (в рамките на първия час) и достигат равновесна грапавост при различни нива,



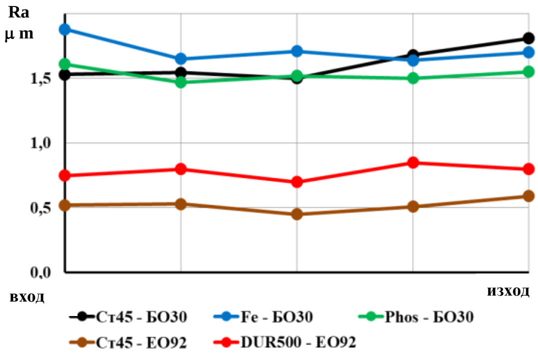
Фиг.4. Изменение грапавостта на триещата се повърхност на изхода на сектора при различен материал на повърхността на ролката

като електрохимичното покритие има два пъти по-висока равновесна грапавост (Ra = 0,80pm) от равновесната грапавост на еталонната антифрикционна сплав (БО-ЗО), при която се достига равновесна грапавост Ra = 0,35 µm, много близка почти равна на равновесната грапавост на ролката (Ra = 0,28 µm).

Разликата в равновесната грапавост на изхода на секторите за възстановените двойки фиг. 3 е по-голяма от тази на входа на секторите за същите двойки фиг. 4. По-голямата. разлика в равновесната грапавост на повърхностите на сектора и ролката от възстановените двоици съответства на по-малко износване при сработването и установеното износване, което се обяснява вероятно с по-доброто образуване и задържане на масления слой.

Равновесната грапавост на триещите се повърхности на изхода на сектора Ra = 1,20 µm, за еталонната двойка е 3,5 пъти по-голяма от равновесната грапавост на входа на сектора. Тази разлика между входа и изхода за сектора на възстановената ролка е два пъти, фиг. 4.

Различен характер на сработване и изменение на грапавостта на повърхностите се наблюдава и на изхода на секторите (фиг. 4). Равновесната грапавост на електрохимичното покритие (ЕО-92) бързо се установява още първия час и достига своите постоянни стойности (Ra = 0,80 µm) еднакви за входа и изхода на секторите, което свидетелства за напълно завършен процес на сработване по цялата триеща се повърхност.



Фиг. 5. Изменение на грапавостта по дължина на триещата се повърхност (вход – изход) на сектора при различен материал на повърхността на ролката

Това се потвърждава и от графиките на фиг.5, които отразяват изменението на грапавостта по дължина на сектора за еталонната и възстановените двоици. Сработването на еталонния антифрикционен слой (БО-ЗО) на изхода на сектора не е завършило и продължава през целия период на изпитване (Ra = 1,20 µm) без да е достигната равновесната грапавост на входа на сектора Ra = 0,30 µm. Разликата между грапавостта на триещите се повърхности на входа и изхода на секторите се вижда много добре от фиг.5, където стойността на тази разлика по Ra е 0,90 µm за еталонния антифрикционен слой.

Увеличаването на равновесната грапавост по дължина на сектора фиг. 5 е най-голяма при еталонната двоица Ra = 0,30-1,20 µm. Изменението на грапавостта по дължина на сектора е по-голямо при възстановените двойки ролка Ra = 0,80-1,50 µm, фиг. 5. Това показва, че сработването по цялата дължина на сектора при възстановените ролки е завършено за времето на експеримента.

Сработването на повърхността на входа на сектора протича много по-бързо от тази на изхода, което се обяснява с различната хидродинамика на триенето и износването на входните и изходни повърхности като тази тенденция е по-добре изразена за сектора работещ в еталонната двойка фиг. 5.

3. Заключение

1. Изменението на грапавостта на еталонната и възстановените с желязно, фосфатно и наварено DUR500 покритие ролки) е еквидистантно, като големината на равновесната грапавост зависи от началната грапавост на триещите се повърхности.

2. По-ниската грапавост на пожелезената, наварената с DUR500 и електрохимичната оловна сплав ЕО92 повърхност на ролката Ra = 0,32 µm от грапавостта на еталонната и фосфатираната ролка Ra = 0,38 µm води до по-малко износване при сработване и установено износване.

3. По-високата равновесна грапавост на двойката с пожелезена ролка Ra =1,55 µm създава по-добри условия за образуване и запазване на масления слой, по-малко износване при сработване и установено износване и по-голяма износоустойчивост при една и съща микротвърдост на работните повърхности.

4. Разликата в равновесната грапавост на изхода на секторите за възстановените двойки фиг. 3 е по-голяма от тази на входа на секторите за същите двойки фиг. 4. Сработването на повърхността на входа на секторите протича много по-бързо от тази на изхода, което се обяснява с различната хидродинамика на триенето и износването на входните и изходни повърхности като тази тенденция е по-добре изразена за сектора работещ в еталонната двойка.

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Theoretical and experimental study of the operational reliability of small-sized agricultural machinery operating in the mountainous conditions of Adjara

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Abstract: *Adjara, with its diverse natural conditions, relief and soil and climatic features, is one of the distinctive regions of Georgia, dominated by mountainous terrain, steep slopes and small areas. Accordingly, the complex mechanization of agricultural processes by mobile agricultural machinery is inappropriate and therefore small-sized agricultural machinery is used. This technique works in difficult soil-climatic and dynamic conditions, it is constantly affected by significant dynamic forces, high humidity, abrasive particles in the environment, mountainous terrain and others. All these factors cause intensive wear and decrease in the reliability of the working bodies of machines. It should be noted that single and complex indicators of the operational reliability of small-scale mechanization equipment operating in the mountainous conditions of Adjara have not been studied and their establishment will contribute to the rational organization of technical service of small-scale mechanization machines.*
The reliability indicators of motoblocks and motor cultivators, such as the probability of failure-free operation, time between failures, the failure rate parameter, the average resource, the coefficients of technical use and readiness, are considered, adequate probabilistic-statistical mathematical models are obtained, the least reliable nodes, types of failures are identified, and a set of measures is outlined to improve reliability.
KEYWORDS: *AGRICULTURAL MACHINERY, MOTOBLOCK, RELIABILITY, PROBABILISTIC-STATISTICAL MODEL, FAILURE.*

1. Introduction: Adjara, due to its natural conditions, relief and soil-climatic features, is one of the original regions of Georgia, in which mountainous relief, steep slopes and low-contour lands predominate. Therefore, the mechanization of labor-intensive agricultural processes with mobile agricultural machines and units is inappropriate and small-sized agricultural machinery is used. The number of such machines of small mechanization, according to official data, is more than 4,000 pieces. Most of them have an engine with a power of 0.1 ... 10 kW. Manufacturers of such machines are Niugoland, Goldon, Kubota, Mitsubishi, and other companies. Mountain conditions and low-contour land adversely affect the operational reliability of small-scale mechanization machines and cause failures. It should be noted that very little design and research work has been carried out in this direction, and the problem of calculating and improving the reliability of small-sized equipment, taking into account local operating conditions, is relevant.

2. Main part: According to pre-prepared logs, statistical data was collected to assess the operational reliability of walk-behind tractors in Kobuleti, Shuakhev, Khulois and Keda municipalities - all failures and their types, time were recorded. spent on their elimination, time to failure and other all the necessary data. Processing of the obtained statistical data was carried out according to the previously compiled by us method according to the NRT plan [1,2]. Received the following series of MTBF of motoblocks:

200; 201; 204; 210; 230; 200; 300; 210; 310; 400; 300; 290; 220; 224; 210; 330; 400; 350; 360; 380; 400; 384; 390; 350; 360; 420; 500; 480; 470; 200; 300; 290; 240; 290; 240; 380; 400; 430; 460; 880; 480; 470; 480; 500; 550; 500; 580; 520; 600; 800; 890; 300; 280; 282; 288; 200; 440; 460; 580; 600; 504; 720; 600; 570; 700; 800; 710; 200; 370; 450; 500; 300; 480; 660; 700; 680; 690; 700; 900; 300; 400; 330; 360; 400; 340; 500; 480; 488; 500; 600; 570; 600; 650; 700; 650; 700; 720; 800; 790; 800; 900; 600.

For mathematical processing of these data and probabilistic-statistical modeling, we compose a variational series of time between failures:

22; 22; 22; 22; 22; 22.1; 22.4; 23; 23; 23; 23; 2 24; 24.4; 25; 26; 26; 30; 30.2; 30.8; 31; 31; 31; 32; 32; 32; 32; 32; 33; 35; 35; 37; 37; 38; 38; 38; 39; 40; 40; 40.4; 41; 42; 42; 42; 42; 42; 42; 42; 45; 46; 47; 48; 48; 49; 49; 50; 50; 50; 50; 50; 50.8; 52; 52; 52; 52; 52; 52.4; 54; 57; 58; 59; 59; 59; 60; 62; 62; 62; 62; 62; 62; 67; 67; 68; 70; 71; 72; 72; 72; 72; 72; 73; 74; 74; 81; 82; 82; 82; 82; 90; 90; 92.

We determine the number of intervals using the Sturgess formula [2] and its width:

$$K = 1 + 3{,}2\ lg\ N = 7$$

$$\mathrm{h} = \frac{X_{max} - X_{min}}{K} = \frac{92 - 22}{7} = 10$$

$\mathbf{K}$ is the number of intervals. $\mathbf{N} = 100$ is the number of motoblocks, h is the number of intervals, $\mathbf{X_{max}}$ and $\mathbf{X_{min}}$ are the maximum and minimum **MTBF** values, respectively. Next, the empirical failure rate and frequency (empirical probability) were determined – **table -1**.

After that, the general characteristics of the time between failures of walk-behind tractors were determined:

Average:

$$\overline{H} = \sum_{i=1}^{k} W_i h_i = 27 \cdot 0.27 + 37 \cdot 0.2 + 47 \cdot 0.18 + 57 \cdot 0.14 + 67 \cdot 0.1 + 77 \cdot 0.08 + 87 \cdot 0.03 = 7{,}29 + 7{,}4 + 8{,}46 + 7{,}98 + 6{,}7 + 6{,}16 = 47\ hours.$$

Dispersion:

$$D = \sum_{i=1}^{k} (H_i - \overline{H})^2 \cdot W_i = (27-47)^2 \cdot 0.27 + (37-47)^2 \cdot 0.2 + (47-47)^2 \cdot 0.18 + (57-47)^2 \cdot 0.14 + (67-47)^2 \cdot 0.1 + (77-47)^2 \cdot 0.08 + (87-47)^2 \cdot 0.03 = 108 + 20 + 14 + 40 + 72 + 48 = 302$$

Table -1. Empirical frequencies and probabilities of failures of walk-behind tractors

MTBF Interval $a \dots b$	Interval midpoint x_i	Empirical frequency m_i	Frequency (empirical probability) W_i
22...32	27	27	0.27
32...42	37	20	0.20
42...52	47	18	0.18
52...62	57	14	0.14
62...72	67	10	0.10
72..82	77	8	0.08
82...92	87	3	0.03
	Sum	100	1.00

Standard deviation:

$$\sigma = \sqrt{D} = \sqrt{302} = 17{,}4 \quad hours.$$

The coefficient of variation:

$$V = \frac{\sigma}{\overline{H}} = \frac{17{,}4}{47} = 0{,}4$$

The failure rate of walk-behind tractors is:

$$\lambda = \frac{\sigma}{\overline{H}} = \frac{1}{47} = 2 \cdot 10^{-2} \quad hours - 1.$$

Differential failure distribution function or probability density:

$$\varphi(\overline{H}) = \lambda e^{-\lambda H_i} = 2 \cdot 10^{-2}\, e^{-2 \cdot 10^{-2} \cdot H_i}$$

Cumulative distribution function:

$$F(H) = 1 - e^{-2 \cdot 10^{-2} \cdot H_i}$$

Probability of trouble-free operation of walk-behind tractors:

$$P(H) = 1 - F(H) = e^{-2 \cdot 10^{-2} \cdot H_i}$$

According to these formulas, the reliability indicators of walk-behind tractors were calculated and the results are presented in **table -2**.

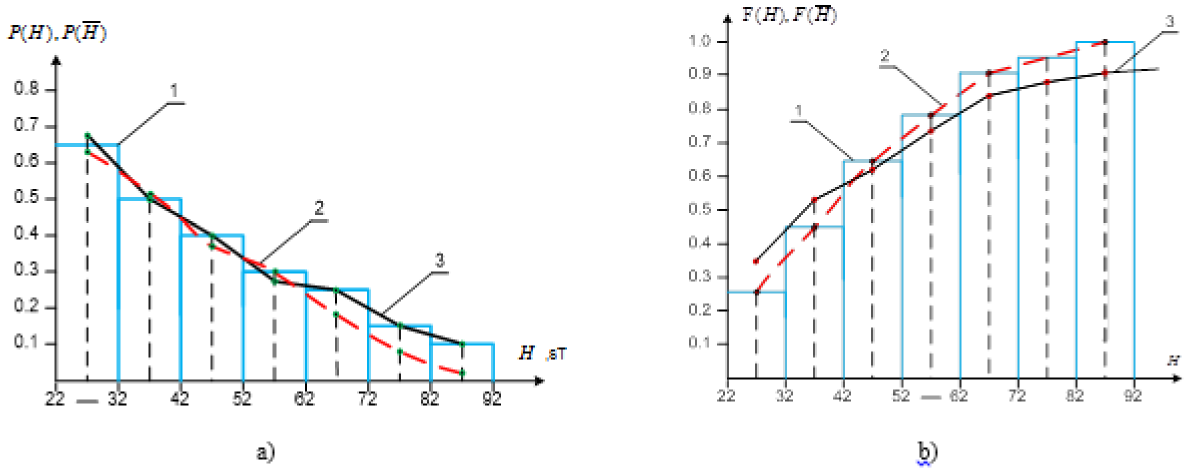
Table -2. The values of the differential distribution function of the time between failures of walk-behind tractors.

MTBF Interval $a \dots b$	Interval midpoint H_i	Empirical frequency m_i	Frequency (empirical probability) W_i	Distribution density (Empirical) $\varphi(\overline{X}) \cdot 10^{-2}$	**П**Distribution density (Theoretical) $\varphi(X) \cdot 10^{-2}$
22...32	27	27	0.27	1.72	1.82
32...42	37	20	0.20	1.30	1.4
42...52	47	18	0.18	1.02	1.06
52...62	57	14	0.14	0.66	0.78
62...72	67	10	0.10	0.52	0.59
72..82	77	8	0.08	0.44	0.48
82...92	87	3	0.03	0.32	0.34

Table -3. *Shows the indicators of operational reliability of walk-behind tractors.*

Table -3. Indicators of operational reliability of walk-behind tractor.

MTBF Interval $a \dots b$	Interval midpoint H_i	Cumulative distribution function		Probability of uptime		Frequency	
		$F(\bar{H})$	$F(H)$	$P(\bar{H})$	$F(H)$	m_i	m_x
22...32	27	0.27	0.34	0.63	0.66	27	25
32...42	37	0.47	0.50	0.53	0.50	20	18
42...52	47	0.65	0.63	0.35	0.37	18	16
52...62	57	0.79	0.74	0.21	0.26	14	13
62...72	67	0.89	0.82	0.11	0.18	10	9
72..82	77	0.97	0.84	0.03	0.16	8	7
82...92	87	1.00	0.88	0	0.12	3	3



Graphical interpretation of research results is shown in **fig -1. a)** and **b).**

Fig -1. Graphs of indicators of reliability of walk-behind tractors **a)** Probability of no-failure operation. **b)** Probability density. **1**. Histogram, **2.** Empirical curve, **3.** Theoretical curve.

Comprehensive indicators of the operational reliability of walk-behind tractors were determined [4]:

Availability factor

$$K_1 = 47/(47 + 12) = 0{,}8$$

Technical utilization coefficient

$$K_2 = 47/(47 + 5 + 12) = 0{,}76$$

Operational indicators of reliability of individual municipalities of Adjara obtained by us are given in **Table -4**.

Table -4. Operational indicators of reliability of individual municipalities of Adjara

Municipality	Mean time between failures $\bar{H}$, hours	Failure rate $\lambda - 1e^{-1} \cdot 10^{-2}$	Probability of uptime $P(\lambda)$	Availability factor K_1	Technical utilization factor K_2
Kobuleti	47	2	0.54	0,8	0.76
Shuakhevi	38	2.6	0.45	0..7	0..66
Keda	36	2,78	0.48	0.65	0.64
Khulo	25	4	0.42	0.6	0.59

Next, the agreement between the theoretical and empirical results was checked using the Pearson criterion [3,4] . For this, it was determined by the $\mathbf{x^2}$ formula:

$$\mathbf{x^2} = \sum_{i=1}^{k} \frac{(m_i - m_x)^2}{m_x}$$

The calculation results are presented in **table -5.**

Table -5. Calculation results. χ^2

MTBF Interval $a \dots b$	m_i	m_x	$\mathbf{x^2}$
200...300	26	24	0.17
300...400	20	18	0.22
400...500	18	16	0.25
500...600	14	13	0.08
600...700	10	9	0.11
700...800	8	7	0.24
800...900	4	3	0.33

The degree of freedom is:

$$r = K - e$$

K - number of intervals. $K = 7$

e - number of binding links and for the exponential distribution: e =2. $r = 7 - 2 = 5$. According to literary sources [2,4] , at and Probability of coincidence of theoretical $\mathbf{x^2} = 1{,}3$ and empirical results $r = 5$.

$$\mathrm{P} = 0{,}5$$

It turns out that the probabilistic-statistical model is adequate.

Failure modes were also investigated and the following results were obtained:

- Construction -30%;
- Manufacturing -26%;
- Operating-44%.

As the analysis of the obtained research results shows, the motoblocks operating in the Kobuleti municipality have the highest operational reliability:

$\overline{H} = 352\ h$, $\mathrm{P(H)} = 0{,}52$

And the lowest in Khuloi municipality:

$\overline{H} = 180\ h$, $\mathrm{P(H)} = 0{,}42$

,

The largest share falls on operational failures, which shows that machine operators grossly violate the rules for the technical use of walk-behind tractors and their qualifications need to be improved.

3. Conclusions: Based on theoretical and experimental studies, the following conclusions can be drawn:

1. A methodology has been compiled and theoretical and experimental studies of the operational reliability of small-sized agricultural machinery operating in the mountainous conditions of Adjara have been carried out;
2. Individual and complex indicators of reliability of motoblocks operating in individual municipalities of Adjara have been determined;
3. The main failures of walk-behind tractors have been established and the expediency of using qualified machine operators when using walk-behind tractors has been proved.

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Method for forecasting engine indicators for its work on different fuels

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***Abstract**: Analysis of physicochemical and operational performance of petroleum and alternative motor fuels showed that their lower heat of combustion can differ significantly. However, the heat of combustion of fuel-air mixtures of these fuels differs slightly. Therefore, the assessment of energy and fuel-economic performance of the engine during its operation on different fuels is proposed to do the calculation method for the consumption and heat of combustion of fuel-air mixtures. According to the developed method, engine power and fuel consumption during engine operation on biodiesel, biomethane and petroleum diesel fuel were determined. To determine the heat of combustion of fuel-air mixtures, the lower heat of combustion of fuels was used. Fuel-air consumption was determined by engine displacement and crankshaft speed. The tests show that the highest power and lowest fuel consumption of the engine running on petroleum diesel fuel and slightly worse values of the engine running on biodiesel. The gas engine with spark ignition converted from diesel running on biomethane shows the lowest indicators.*

***Keywords:** PETROLEUM DIESEL FUEL, BIOFUEL, HEAT OF COMBUSTION, FUEL-AIR MIXTURE*

INTRODUCTION

Nowadays, each country has a large mobile fleet of agricultural machinery with diesels which operate on diesel fuel from oil. But the price of diesel fuel increases all the time. The environmental situation is deteriorating. One of the main ways out of this situation is adapting of diesel engines to work on alternative fuels [1-3], which include biofuels: bioethanol, biodiesel, biogas, which belong to renewable energy sources and is a product of agriculture. But the implications of alternative motor fuels are ambiguous. This is due to differences in the physico-chemical properties of these fuels.

Energy indicators represent a significant interest in the use of biofuels. Energy efficiency, operation stability of an engine was determined by bench tests of the engine. This process requires of expensive equipment. The aim of the study is to evaluate energy and fuel-economic indicators of the engine working on the biofuels and petroleum diesel oil.

PRERQUISITES AND MEANS FOR SOLVING THE PROBLEM

To find out, biofuels (bioethanol, biodiesel, biogas) will solve this problem, we evaluate the physical-chemical and operational characteristics in comparison with conventional fuels (tabl.1) [4-6].

***Table 1.** Physico-chemical and performance characteristics of traditional and alternative fuels*

Index	Diesel fuel (summer)	Compressed natural gas	Bioethanol	Biodiesel fuel	Biogas
Viscosity at 20°C, mm^2/s	3,5–6,0	–	1,76	3,5–8,0	–
Octane number		100–110	106	20–25	115 –
Cetane number	40–45	–	8	50–55	–
Ratio C/H	6,5	3	4	6,5	–
Lower heat combustion MJ/kg (MJ/m^3)	42–43	49–50	25	37–38	17–23
The heat of combustion of the fuel-air stoichiometric mixture MJ/m^3	3,4	3,2	3,6	>3,4	≤3,0
The amount of air needed for complete combustion of 1 kg of fuel, kg	14,0–14,5	17,0–17,5	8,5	13,5–14,5	3,5–10,2

Lower combustion temperature of fuels differs greatly. The heat of combustion of fuel-air mixtures for various liquid fuels is little different and is not proportional to the heat of combustion of appropriate fuels. This can be explained as follows. The amount of air required for complete combustion of 1kg of fuel depends on the same variables and lower heat of combustion. The more oxygen is consumed for combustion of the fuel, the more heat is allocated. The heat of combustion of the fuel-air mixture depends on the elementary composition of the fuel and the amount of air in the fuel-air mixture.

Natural gas and alcohol fuels, the esters do not contain sulfur, olefin and aromatic hydrocarbons. Environmental problem of protection from sulfur-containing compounds, polycyclic aromatic carbohydrates and other harmful substances practically disappears when used. Note that the introduction of gasoline alcohols and their derivatives increases the octane number of gasoline. It takes the edge off of the need out of leaded gasoline, but also reduces the content of aromatic hydrocarbons. More complex is the question of the relationship of the parameters of the engine's power and toxicity of combustion products.

Emissions of hydrocarbons, carbon monoxide and nitrogen oxides are reduced when using the alcohols and gaseous fuels. Fuel consumption increases by about half when using alcohols and and increases slightly when using biodiesel fuel. Power parameters of the engine, on the contrary, in the case of the alcohols slightly rising and and reduced when operating on gaseous fuel. Since the use of bioethanol in diesel engines is problematic, we will consider biodiesel and biogas in the future. The use of biogas in diesel engines is possible in two directions his conversion: in diesel engine and gas engine with spark ignition [6]. Most commonly used esters of rapeseed oil as biodiesel fuels: methyl and ethyl.

SOLUTION OF THE EXAMINED PROBLEM

The authors use the link between useful work (effective power N_e, which is obtained at the output of the engine) and the amount of heat Q_e expended to obtain it to calculate engine power [7]:

$$Q_e = N_e = H_{sm} \cdot \frac{B_m}{3,6 \cdot 10^3} \cdot \eta_e, \text{ mWh,} \quad (1)$$

where Hs_m – heat of combustion of the fuel-air mixture, MJ/m^3;

B_m – hour consumption of the fuel-air mixture, m^3/h;

η_e – effective efficiency of the engine.

The calorific value of the fuel-air mixture of stoichiometric composition (when the excess air ratio equal to one) are shown in table 1 and other sources. However, diesels in all modes work on poor mixtures.

The heat of combustion of the fuel-air mixtures of different fuels:

$$H_{sm} = \frac{H_u - \Delta H_u}{\alpha \cdot L_0} \cdot \eta_e \quad (2)$$

where H_u – lower heat of fuel combustion, MJ/kg (MJ/m^3 for gas fuels);

ΔH_u – chemical incompleteness of fuel combustion, MJ/kg (MJ/m^3);

α– coefficient of excess air, which characterizes the composition of the fuel-air mixture (poor or rich);

L_0– amount of air required for complete combustion of 1kg of fuel theoretically.

At the previous stage of the nature of the change η_e is accepted the same as for the basic engines, although mechanical losses of the engines on alternative motor fuel (AMF), in particular on gas fuel are considered lower by improving lubrication conditions.

The expense of the fuel-air mixture for a particular engine design is determined by the formula:

$$B_m = \left(\frac{V_h \cdot i}{1000} \cdot \frac{60 \cdot n}{\tau}\right) \cdot \frac{T_0 \cdot P_a}{T_a \cdot P_0} \cdot \eta_v \cdot \gamma \text{, m}^3\text{/h} \quad (3)$$

where V_h, i – volume and number of cylinders;

τ – cycle of engine;

n – rotation frequency, min^{-1};

η_v– coefficient of admission;

T_0, T_a, p_0, p_a – accordingly, the temperature and pressure of the environment and and the working fluid at the end of the intake;

γ = 1,11 ... 1,14 – coefficient of completeness of charge taking into account the delay closing the intake valve.

The consumption of liquid and gas fuels are given to a common unit: by effective specific fuel consumption g_e is determined by the specific consumption of heat introduced into the engine with fuel:

$$q_e = g_e \cdot H_u \text{, Mj/kWh·h} \quad (4)$$

where g_e – effective specific fuel consumption in kg / kWh*h (m^3 / kWh*h).

RESULTS AND DISCUSSION

Need to know the lower calorific value of the fuels to determine engine power. But this value is usually unknown for new fuels. This situation was with new biodiesel – isopropyl ester of rapeseed oil (IERO).

The elementary composition (carbon C, hydrogen H and oxygen O) isopropyl ester of rapeseed oil (IERO) according to the acid content in rapeseed oil was determined [8]: ester of erucic acid – 50,0 %, oleic – 29,0 %, linoleic – 15 %, other esters of other acids (table. 2).

The lower calorific value, IERO was determined by the elementary composition of the fuels and known formula of D. Mendeleev. The indicators of diesel fuel (DF), methyl ester of rapeseed oil (MERO) and ethyl ester of rapeseed oil (EERO) are provided for comparison in table 2. A smaller portion of the carbon in the molecules of biodiesel fuels leads to reduction their lower heat of combustion. The increased oxygen content leads to intensification of the combustion process. The result is the reduction of soot in the exhaust gases.

Table 2. *Chemical and energy characteristics of petroleum diesel and biodiesel fuels*

Indicator of fuel	DF	MERO	EERO	IERO
Fuel composition, %				
carbon C	87,0	77,5	77,54	76,28
hydrogen H	12,6	12,0	12,04	13,16
oxygen O	0,4	10,5	10,42	10,05
Theoretically required amount of air for combustion of 1 kg of fuel, kg	14,45	12,70	12,73	12,98
The lower heat of combustion, MJ/kg	42,44	37,50	37,56	38,33

In order to perform calculations adopted dependence of the heat of combustion of the fuel-air mixtures Hs_m various fuels for different values of the coefficient of excess air (fig. 1). According to thermal calculations of an engine for different rotation frequencies installed the changes of coefficient of admission for the engine during its operation on various fuels.

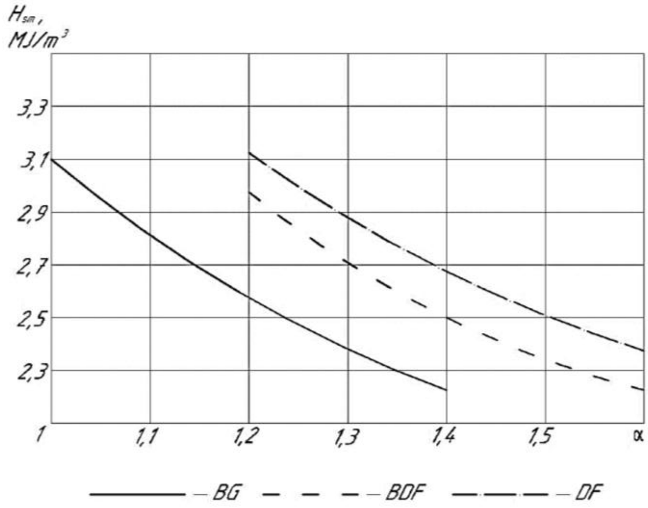

Fig. 1. *The dependence of the heat of combustion of fuel-air mixtures of different fuels from the composition of the mixture (BG – biogas; BDF – biodiesel fuel (in this case, IERO); DF – diesel fuel)*

Low methane content (60 %) and a significant number of ballast are problematic enough to power mobile energy resources due to use of biogas. Carbon dioxide causes a decrease in power. The hydrogen sulfide contained in biogas causes corrosion of engine parts.

Purification indicators of biogas from carbon dioxide and other impurities can be adapted to indicators of natural gas and improve energy and economic indicators of the engine operating on biogas significantly. With the increase of methane content in the biogas (using different purification methods), the indicators of lower heat of fuel combustion, the effective capacity are increasing. However, the effective specific consumption of gas decreases. The methane content in the biogas is 90 %.

The high octane number of biogas (115–130) gives the possibility for a significant increasing the compression ratio of the engine (up to 13 units) and increasing the efficiency of the engine.
Effective power N_e belongs to the energy indicators of the engine. Fuel efficiency of the engine when operating on liquid and gaseous fuels is evaluated by specific consumption of heat per unit effective power (table. 3).

Table 3. *Energy and fuel-economic indicators of engine D-243 when operating on different fuels*

Fuel	Effective engine power N_e, кWh	Effective specific heat rate g_e, MJ/ кWh*h
DF	56,0	8,0
Biodiesel	54,0	9,0
Biogas (methane content 90 %)	53,5	10,2

Table 3 shows that the engine power and its fuel efficiency increases with increasing of heat of combustion of the fuel-air mixtures (tab.1). However, the energy indicators of the engine would be easier to compare by one indicator. Such an indicator may be a mechanical equivalent of one MJ of fuel.

Road fuel consumption and road emissions of the harmful substances of the technological vehicle during the work on different fuels were determined by mathematical modeling. Comparison of fuel and economic and ecological indicators of engines during the work on different fuels was carried out according to experimental load and speed characteristics, described by polynomial models (fig. 2).

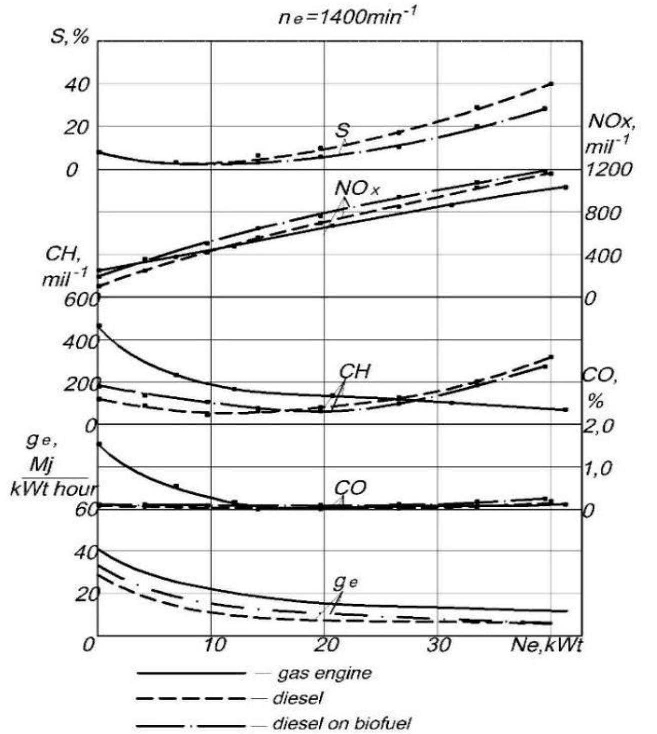

Fig. 2. *Load characteristics with measurement of toxicity of exhaust gases of the engine D-243 when working on different fuels at the frequency of rotation of the crankshaft 1400 min^{-1}*

Note: N_e = effective engine power; g_e = specific effective fuel consumption in Mega Joule of energy at kWt hour

A track fuel consumption and travel emissions of a tractor, being operated on different fuels, are defined by mathematical modeling. The calculations showed that the tractor with a diesel engine, being driven on the adopted driving cycle, consumes (accordingly, on average) 22 % less fuel, and its CO emissions are 47 % less and CH emissions are 90 % less than of the tractor with a gas engine.

This is due to the fact that the gas engine in all modes runs on richer fuel-air mixtures. A tractor with the diesel engine emits nitrogen oxides NO_x 4 % more. It also emits soot unlike the tractor with the gas engine. Comparing the total specific emissions of harmful substances (HS), converted to carbon monoxide ΣCO, taking the relative aggressiveness, it is clear that the tractor with a diesel engine is (36 %) more toxic. The total toxicity of a tractor engine running on biodiesel fuel is also lower than of an engine on oil fuel. But the number of emissions of harmful substances in the exhaust gases does not allow to analyze the environmental safety of the tractor.

CONCLUSIONS

The power of the diesel engine while operating on biofuels is less in comparison with operation on oil fuel. Fuel consumption is more due to the lower heat of combustion of these fuels. The energy indicators of fuels are more appropriate to evaluate for the heat of combustion of fuel-air mixtures. With increasing of the heat of combustion of fuel-air mixtures increases engine power and reduces fuel consumption.

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Mathematical modeling of features of electrophysical processes in a vibration plow with piezoelectric actuator

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Abstract: *In the process of studying multiphysical processes, including electrophysical ones, the resonance frequency at which the piezoelectric actuator maximally influences the amplitude of oscillations of the plow blade was established in the COMSOL Multiphysics software package. The maximum amplitude of oscillations of the plow-piezo actuator system and the rational location of the piezo actuator on the dump, which provides an efficient vibration process, have also been determined. The performed numerical experiments allowed to obtain approximation expressions for simplified determination of the amplitude of oscillations of the system depending on the coordinates of the piezo actuator on the heap. The research results can be used in the design of vibrating soil cultivation bodies in agricultural machinery.*
Keywords*: PIEZOCERAMIC ACTUATOR, VIBRATION TECHNOLOGIES, COMSOL MULTIPHYSICS, APPROXIMATE DEPENDENCES.*

1. Introduction

Agriculture is one of the leading branches of the production sphere, which is engaged in the cultivation of agricultural crops. The main task of agriculture is to provide the population with food and raw materials for industry. The food security of the state and its citizens depends on the state of agriculture [1]. One of the main problems of agriculture is the complexity and efficiency of land cultivation. The process of loosening the soil with a wedge is one of the most common ways to improve its properties [2]. Loosening the soil is created through the use of conventional plows. Therefore, their improvement as the main devices for soil cultivation is a reliable way to improve the efficiency of tillage [3]. One of the areas of improvement is to combine plows with actuators and thus obtain vibrating plows, which are more efficient in processing than conventional ones.

An actuator is an actuator or its active element that converts one type of energy (electrical, magnetic, etc.) into another (most often - into mechanical), which leads to the performance of a certain action specified by the control signal. [4-8]. The properties of the actuator depend on the physical effect on which they work.

Modern vibrating plows are improved through the use of electromagnetic actuators and hydraulic actuators. One alternative type of actuator is the piezo actuator. The piezo actuator is a piezomechanical device that operates on the basis of the reverse piezoelectric effect and is designed to actuate mechanisms and systems, ie the determinants of its performance are electrophysical and mechanical processes in their interaction. The main advantages of piezoelectric actuators (PA) are the ability to create significant effort when moving, while having a minimum size. This allows them to be easily integrated into power systems [4-8]. In addition, PAs are characterized by simplicity of design and high reliability during operation.

However, the theoretical basis for the use of piezoelectric actuators in soil cultivation bodies is almost non-existent. Thus, the creation of certain theoretical recommendations based on complex mathematical modeling of electrophysical and mechanical processes in the system "plow dump-PA" for the design of vibrating plows using PA is relevant.

2. Description of the analyzed vibrating plows

Experimentally established [9], that when using vibrations in plows the friction of sliding of soil on a ploughshare and a shelf which are elements of a plow which is the main component in the general size of traction resistance considerably decreases. The stickiness of the working bodies is also reduced. This leads to a reduction in fuel consumption, reduces wear of parts of agricultural machinery and cultivation bodies, ie increases its service life and reduces the processing time of the site. In this regard, new designs of plows with vibrating working bodies have recently appeared. One such plow with an electromagnetic actuator [9] presented in fig. 1.

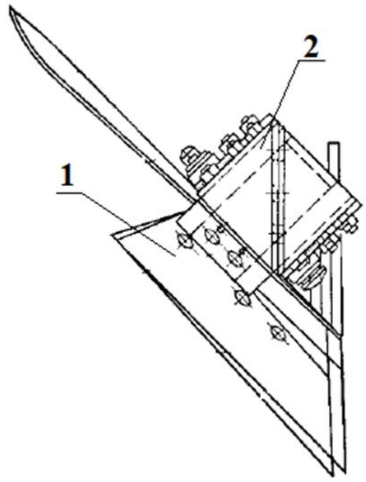


Fig.1. *Vibrating plow body with electromagnetic vibrator: 1 - blade; 2 - electromagnetic actuator*

The principle of operation of the vibrating plow with an electromagnetic vibrator is as follows. Current pulses are fed to the coil of the vibrator electromagnet, forcing the armature together with the moving part of the working body with a frequency of about 50 oscillations per second. In the absence of current pulses under the action of the soil reaction, the actuator armature is squeezed. The obtained oscillations of the moving part of the working body are directed normally to the blade of the ploughshare. The obtained experimental data showed a positive effect [9]. However, it should be noted that the main disadvantages of this design are quite large dimensions, relatively high current consumption and low oscillation frequency of the blade.

Also noteworthy are two general-purpose plow designs with hydraulic semi-automatic and automatic vibrator adjustment. The design of these plows is developed on the basis of plow PN-3-35. The rack of each case is cut into two parts, which are hinged to each other. The upper part of the rack is attached to the plow frame, and the lower is connected to it by a hinge, which is located below the conditional center of resistance of the body. Displacement of the hinge from the center of resistance provides the necessary force for automatic adjustment of vibration modes [9]. The design of a plow with such an actuator is quite complex and, as a result, not very reliable.

In the works [1, 10] the development of a vibrating plow with the use of PA is presented. Unlike other vibrating plows, its PA version is much smaller and heavier, has a high efficiency, is characterized by a wide range of control excitation frequencies and the creation of significant forces during vibration. However, these studies did not conduct or present the results of studies that substantiate the approximate optimal location of the PA on a regular plow heap cultivation tool based on multiphysical modeling of its characteristic processes that directly affect its efficiency. Therefore, the implementation of the above tasks is an urgent application problem that needs to be solved.

Materials and methods. To study the influence of electrophysical and mechanical processes in their interaction on the vibrational oscillations of the system "plow dump-PA" was conducted a series of numerical experiments using the software package COMSOL Multiphysics 3.5.

The COMSOL program interface combines the functions of modeling modules of solid mechanics COMSOL's Solid Mechanics and electrostatics Electrostatics into one computing tool for modeling piezoelectric materials. Modeling of piezoelectric devices in COMSOL Multiphysics 3.5 is carried out using the Piezoelectric Effects module. Since the operation of the PA is based on the inverse piezoelectric effect, so in the module Piezoelectric Effects selected mode Stress-Charge Form [11, 12]. The piezoelectric element is characterized by the connection between mechanical deformations and the electric field, which is determined by the material and constitutive relations [13-15]:

$$\begin{gathered} \nabla \cdot D = \rho; \\ \nabla \cdot T = 0; \\ T = c_E S - e^T E; \\ D = eS - \varepsilon_S E; \\ c_E = S_E^{-1}; \\ e = ds_E^{-1}; \\ \varepsilon_S = \varepsilon_T - ds_E^{-1} d^T; \end{gathered} \tag{1}$$

where T – mechanical stress;

S – deformation;

E – electric field strength;

D – electric field displacement;

c_E – elastic matrix (tensor of the 4th rank c_{ijkl});

e – communication matrix (tensor of 3rd rank e_{ijk});

d – matrix of piezo modules (tensor of 3rd rank d_{imn});

ε_S – dielectric constant matrix (tensor of the 2nd rank ε_{ij});

ρ – free charge density;

ε_T - dielectric constant of piezoelectric material.

For multiphysical finite element mathematical modeling of processes, as in [12], Lagrange finite elements with elementary basic functions of the second order - Lagrange-Quadratic - were used. The calculated mesh of finite elements in the item "Mesh" was chosen orthogonalized with the normal size of the elements Normal. Direct was used as the Solver, in which the numerical SPOOLES method was chosen to solve a system of linear equations with sparse matrices.

Modeling of the piezoceramic plate was performed under the condition of its production from PZT-5H brand material. Strucrtural Steel material was used for the metal part of the investigated system, ie the plow blade, for similar purposes. The overall dimensions and geometry of this cultivation organ are illustrated in fig. 2, which also indicates one of the options for placement of PA.

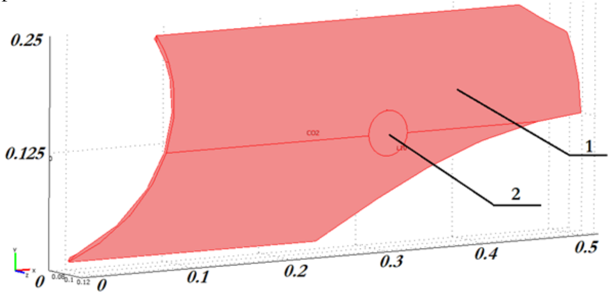
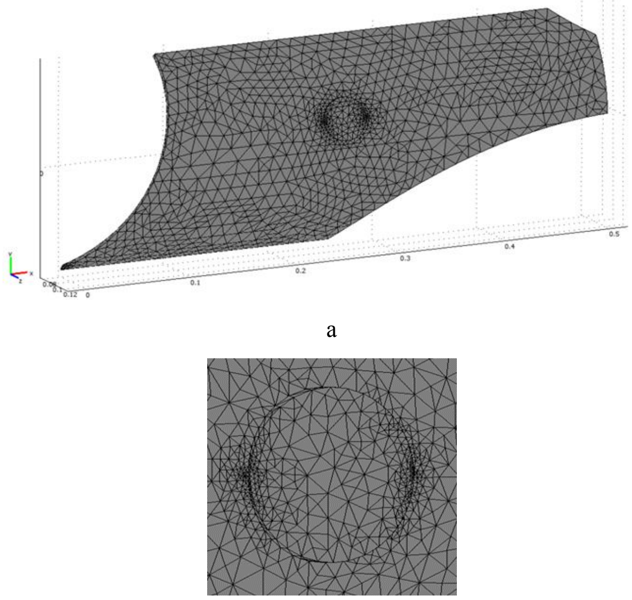


Fig. 2. *Plow blade with piezoelectric actuator: 1 - dump; 2 - disk piezoelectric actuator*

The studied three-dimensional model of the system "plow dump-PA" is represented by a set of finite elements obtained by constructing a grid with tetragonal partition. The corresponding CAD model of the system is illustrated in Fig. 3.



a

b

Fig. 3. *Three-dimensional CAD-model of the system "plow dump-PA": a - general view; b - area of PA placement*

The following limit conditions were set during modeling: for electrical processes - supply of electric voltage and zero potential to diametrically opposite sides of the PA, respectively electric potential and ground (the side of the PA adjacent to the surface of the dump); for mechanical processes, the lower surface of the piezoceramic disk, which is the support and placed on the shaft, was fixed, and the opposite - the possibility of free movement.

Results. To conduct modeling, we first determine the overall dimensions of the PA. Among the standard sizes of piezoceramic disks produced by the industry, we will choose the one that has the maximum diameter and allows at the same time a full-fledged fit to the curved surface of the blade at any point of its connection. These conditions are satisfied by PA with a diameter of 45 mm. Conditionally apply a uniform grid on the surface of the dump with the dimensions of the cell 45x45 mm, which allows you to inscribe in it a circle with a diameter equal to the diameter of the selected piezo-frame disk. This grid, shown in fig. 4, determines the possible locations of the PA on the dump when searching for its position, which provides the maximum vibration effect of the entire system "plow dump-PA".

Grid cells with code A2, A11, B2, C2, C10, C11, D2, D8-D9, E1, E7, F1-F6 cannot be considered as possible for PA placement for obvious reasons. In other cells of the grid, except for those that do not overlap on the surface of the dump, alternately placed PA, followed by computer simulation of multiphysical processes, which are crucial for the implementation of the necessary oscillations of the system under study.

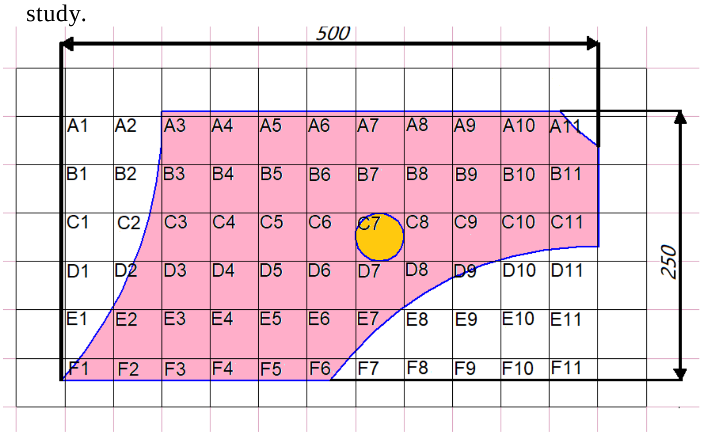
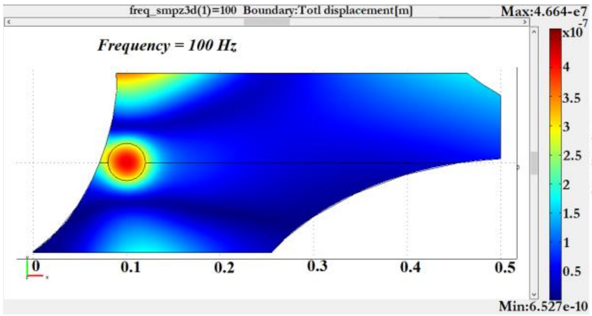


Fig. 4. *Drawing a grid and coding its cells on a plow dump*

At the first stage of modeling to determine the limits of the operating frequency range of the system numerical experiments were performed in Eigenfrequency mode, ie determining the natural frequencies that depend only on material properties, geometry and dimensions of PA, mechanical boundary conditions. This makes it possible to carefully study the amplitude-frequency characteristics of the system "plow blade-PA" near the natural frequencies, where it is possible to observe resonance. The values of the first six natural frequencies of the system were determined. For example, for cell C6, they are in the range from 100 Hz to 1000 Hz.

Further in the mode of Frequency Response Analysis, ie analysis of the frequency response when applying to the PA alternating sinusoidal voltage, the next stage of research was conducted to determine such a cell grid to accommodate the PA, which is best to achieve maximum propagation of oscillations.

Some examples of the results of numerical experiments are shown in fig. 5.



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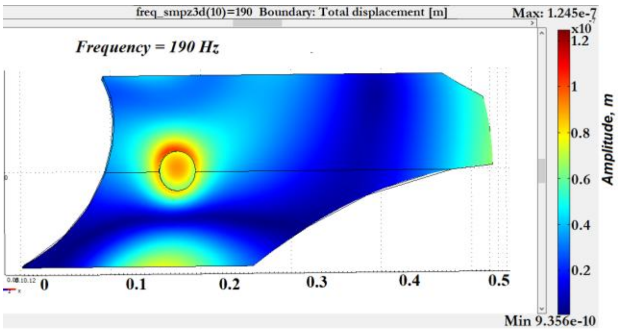

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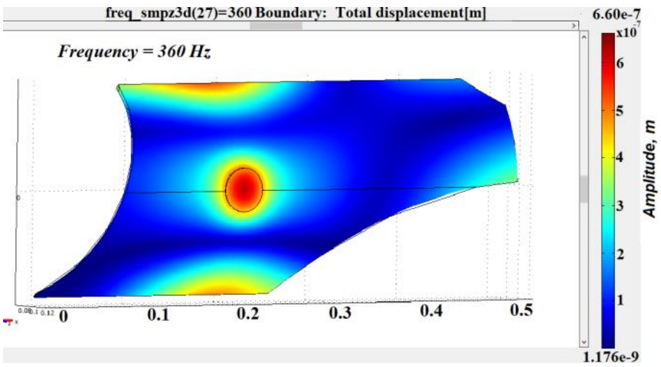

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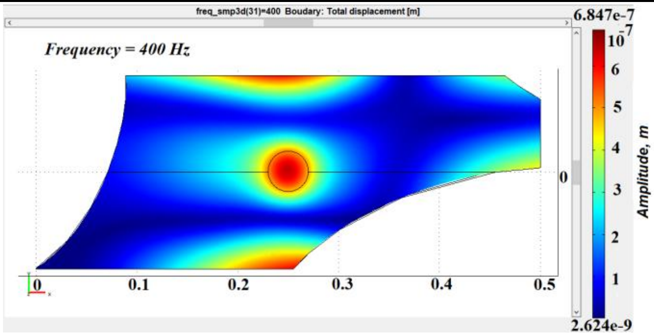

d

Fig. 5. Examples of determining the oscillations of the system "plow dump-PA", which were obtained in different cells of the grid: a - cell C3; b - cell C4; c - cell C5; d - cell C6

The image of Fig. 5 contain the given color scale of gradation of amplitude of oscillations of the system "plow dump-PA" and the corresponding numerical indicators shown on the right on the vertical axis. Numerical frequency values in the postprocessor window of the COMSOL Multiphysics package are displayed automatically and correspond to the maximum amplitude of PA oscillations. Analysis of the results of research suggests that the most rational location of the PA on the dump is cell C6 (Fig. 5 d), where at a frequency of 400 Hz there is an amplitude of oscillations of the system in the range $2.624 \cdot 10^{-9}$ – $6.847 \cdot 10^{-7}$ m.

In addition, according to the simulation results, approximate expressions of the change in the amplitude of oscillations of the system depending on the coordinates of the PA location on the plow heap were obtained. It was believed that the coordinate system is located in the lower left part of the plow blade.

$$A = a + by + cy^2 + dy^3, \qquad (2)$$

where A is the oscillation amplitude of the system; x is the corresponding coordinate of the PA location on the dump (0.1 < x < 0.2);
$a = 7.4609 \cdot 10^{-6}$, b = -0.00013040883, c = 0.000727255,
d = -0.0012261667– coefficients;

$$A = f + ky + gy^2 + hy^3 + jy^4, \qquad (3)$$

where y is the corresponding coordinate of the PA location on the dump (0.1 < y < 0.15),
$f = -2.00368 \cdot 10^{-5}$, $k = 0.00073820533$, $g = -0.0095278667$, $h = 0.052941867$, j =-0.10683733.

Conclusion

In the process of studying multiphysical processes, including electrophysical ones, the resonance frequency at which the piezoelectric actuator maximally influences the amplitude of oscillations of the plow blade and which is equal to 400 Hz. The maximum amplitude of oscillations of the "plow dump-PA" system, which is $6.847 \cdot 10^{-7}$ m, and the rational location of the piezo actuator on the heap, which provides this effect. The performed numerical experiments allowed to obtain approximation expressions for simplified determination of the amplitude of oscillations of the system depending on the coordinates of the piezo actuator placement on the heap.

The results of research can be used in the design of vibrating plows based on piezoceramic actuators.

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Determınatıon of the dust concentratıon of hazelnut threshıng machınes

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Abstract: *This study was carried out to determine the dust concentration values formed in the environment during the use of hazelnut threshing machines, determine the effects on the employees, and reveal solution suggestions to reduce the dust concentration value. The most distinctive difference that distinguishes Turkish hazelnut varieties from other country varieties is that the fruit husks of Turkish varieties are long and tightly wrap the fruit, and threshing is required. During the threshing process, dust particles (fine soil, sand, husk and grass particles, Etc.) are dispersed intensively from the husk-blowing unit of the machine and the air outlet of the fan. A handheld particle measuring device with a particle size range of 0.3…5 µm was used to determine the dust concentration emitted from the machine to the atmosphere during the blending process. As a result of the measurements, dust concentrations of* PM_1 *(1 µm),* $PM_{2.5}$ *(2.5 µm), and* PM_5 *(5 µm) were determined in* $\mu g/m^3$ *air. The dust levels formed in the environment during the hazelnut threshing machines were compared by considering the dust concentration threshold limit of 4* mg/m^3 *air specified in the occupational health and safety legislation and regulations.*
Keywords: *PARTICULATE MATTER, DUST CONCENTRATION, HAZELNUT THRESHING MACHINE*

1. Introduction

Solid particles of various sizes (1-100 µm) that can hang in the air for a certain period are called 'dust' [7]. Atmospheric dust is defined differently, but the most used classification is "total suspended dust" and "particulate matter". Dust particles have severe and essential effects on human health [2]. As a result of exposure to dust in the working environment, different respiratory diseases and diseases occur depending on the concentration, active substance, exposure time, age, gender, and smoking habit. Dust particles are divided into three groups according to their particle size inhalable, total inhalable, and total dust. The aerodynamic diameter of respirable dust is between 5…10 µm, while the diameter of total respirable dust is between 0.5…5 µm. Respirable dust is the dust group that poses the greatest danger of causing diseases in the lungs, and total respirable dust is the dust group held in the nose, throat, and upper respiratory tract [10, 17].

Different limit values have been determined for personal exposure to organic and inorganic dust by different organizations worldwide. These limit values are not created according to ideal conditions but based on technical feasibility and realistic goals that can be reached as a result. In this case, factors such as the awareness and education level of the practitioners and the efficiency and affordability of engineering solutions are determined to bring the personal exposure limit values to a practical level, and new limits are set when the targeted success is achieved [3].

Agricultural activities are a significant source of atmospheric particulate matter (PM) emissions [20]. Concentrations of dust in the environment, exposure time, and body resistance are effective in the disease of agricultural workers. It is reported that there are approximately one billion bacterial and fungal organisms in one gram of dry soil [7]. Some diseases that occur due to dust exposure in the agricultural sector are asthma, rhinitis, bronchitis, farmer's lung disease, organic toxic dust syndrome, and diseases related to microorganisms. In Turkey, it has been reported that asthma and rhinitis due to exposure to grain dust and asthma diseases due to organic dust are seen in the agricultural sector [8]. Studies indicate that the primary dust sources are wind erosion. However, the most common dust exposure among agricultural processes is in tillage, harvesting, post-harvest processing, fertilization, stubble burning, pesticide use, and livestock [19, 21]. The aerodynamic diameter of dust generated in agricultural processes is reported as $PM_{2.5}$ and below [19]. It is stated that the most intense dust emissions occur in tillage and harvesting processes in Europe and North America and are above the respirable threshold limit values [22, 23]. In the study carried out to determine dust emissions due to soil moisture in cotton, wheat, and tomato harvest, it was reported that dust emission values are above the respirable threshold value. However, the density of dust depends on soil moisture and season. The highest dust emission occurred during picking in the cotton harvest, which consists of picking and straw cutting processes. The most intense dust emission values in cotton, wheat, and tomato harvest were in tomato, wheat, and cotton harvesting processes, respectively [22]. In the Northern European Plains, dust emission induced by tillage was measured four to six times higher than dust emission by wind erosion events [24]. Another study reported that dust from the soil during the hazelnut harvest poses a risk for the population living nearby, especially those working in specialized areas of hazelnut cultivation [17]. In a study conducted to determine the dust emissions of a hazelnut harvester working with vacuum effect, around the harvested area, into the area, and to the operator, dust emission values were found to be very high for all points PM_{10} dimension. The operator's area measured the most intense dust exposure [16]. The study conducted with self-propelled hazelnut harvesters with mechanical effects reported that the grassy ground and moist soil reduced the dust emission values [1, 26]. In the study conducted with hazelnut harvesters with mechanical and pneumatic effects, it was reported that the resulting dust was well above the ACGIH (American Conference of Governmental Industrial Hygienists) respirable dust threshold values. Depending on the working principle of the pneumatic hazelnut harvesters, it has been stated that the dust emission is high, and the pre-sweepers of the mechanically effective hazelnut harvesters have intense dust emission during the operation [9].

The absence of foreign material cleaning unit in hazelnut threshing machines used in Turkey increases the amount of dust generated. There is no data on the dust concentration values emitted in the environment during the threshing of hazelnuts with hazelnut threshing machines. For this purpose, it was carried out to determine the dust concentration values formed in the environment during the use of hazelnut threshing machines, determine the effects on the employees, and reveal solution suggestions to reduce the dust concentration value.

2. Material and Method

2.1. Material

Dust measurements were made in a farmer's hazelnut orchard in the Samsun Terme district. The hazelnut orchard, where the experiments were carried out, has a common cultivar of Çakıldak hazelnut in the region. Some characteristics of the Çakıldak hazelnut variety are given in Table 1.

Table 1. *Some characteristics of Çakıldak hazelnut variety*

Kernel moisture, %	13,86
Hulled grain moisture, %	16,85
Shell moisture, %	21,87
The humudity of the husk, %	22,21
Dimensions (Thickness, length, width), mm	18,24 x 18,01 x 16,22
Thousand-grain weight, g	1699,5
Shell thickness	1,24
Husk features	long, tapering to the tip

AeroTrak APC 9303-01 model hand-held particle measuring device with dust concentration and particle size range of 0.3…5 µm of hazelnut threshers were used.

Hazelnut threshing machine manufactured by local manufacturers; It consists of 4 central units: feeding unit, husk peeling unit, lower separation system, and upper separation system (Figure 1).

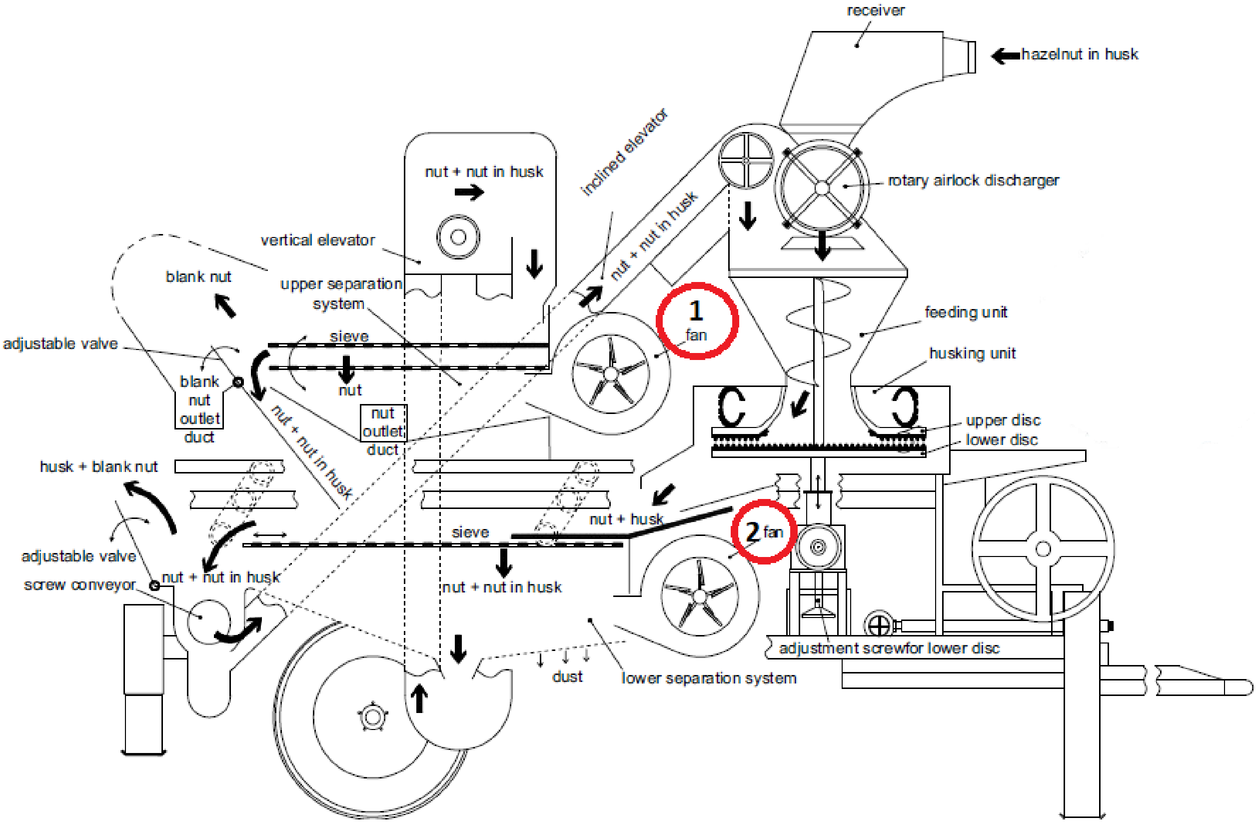

Figure 1. *Hazelnut threshing machine [6].*

A suction air transmitter provides the transmission of husked hazelnuts to the feeding unit with a transmission hose, whose separator and unloader are mounted on the feeding unit. The husked hazelnuts, which are discharged into the feeding unit, are conveyed to the husk peeler unit from the upper disc center with the spiral conveyor in the hopper. The husk peeler unit consists of two metal discs, and the husk peeling surfaces are covered with rubber discs with radial profiles.

The lower separation system consists of one flat screen placed horizontally, a double suction radial fan, and an adjustment flap placed at the outlet of the separation system. The flat sieve is placed in a slide bed, and depending on the husk moisture content of the blended hazelnuts, it can be adjusted back and forth to increase the husk flaking efficiency. In the lower separation system, the peeled hazelnuts and some single-grained hazelnuts and husk pieces are sieved and conveyed to the upper separation system with a vertical elevator. The upper separation system consists of two flat sieves, a double suction radial fan, and an adjustment flap placed at the outlet of the separation system. The angle of the sieves with the horizontal can be adjusted within the range of ±5°. While the hazelnuts sieved in the sieves are taken from the grain channel, the hazelnuts that cannot be sieved and blown flow back to the sieve in the lower separation system over the inclined surface. The outlet of the upper separation system is closed with a round hole sieve, and the empty hazelnuts and husk pieces, which are blown by the airflow created by the fan, are taken from the empty hazelnut channel.

In the operation of the machine, a standard agricultural tractor, which is in the 40…60 kW power group, is used as the power source, and the tractor is operated at an average engine speed of 1350 min^{-1} [6].

2.2. Method

In dust measurement trials, hazelnut threshing machines manufactured by local manufacturers were used. During the trials, no intervention was made regarding the adjustment levels of the hazelnut threshing machines. The hazelnut threshing machine was operated during the trials at 1290 min^{-1} fan shaft speed, 740 min^{-1} sieve eccentric rotation number, and 310 min^{-1} rotations of the moving disc in the husk peeler unit. In order to determine the dust concentration values of the hazelnut threshing machines, measurements were made with the dust measuring device at the height of 1.5 m from the ground for 30 minutes and with three replications. We determined the measuring points so that the operator would be in the working area during hazelnut threshing with hazelnut threshing machines. Measurements were made at eight different points, 1, 2, 3, 4, 5, 10, 20, and 25 m from the machine. The average of the dust concentration values obtained at these points is given. As a result of the measurements, dust concentrations of $PM_{1.0}$ (1 µm), $PM_{2.5}$ (2.5 µm), and $PM_{5.0}$ (5 µm) were determined in µg/m^3 air. The dust levels formed in the environment during the hazelnut threshing machines were compared by considering the 4 mg/m^3 air value, which is the dust concentration threshold limit specified in the occupational health and safety legislation and regulations.

3. Results and Discussion

During the trials, the average air temperature was 24.1℃, the humidity was 57.8%, and the wind speed was measured as 0.4-0.3 m/s. The lowest and highest measuring ranges of the dust concentrations formed in the environment during the threshing of hazelnuts according to the diameter groups $PM_{1,0}$, $PM_{2,5}$, and $PM_{5,0}$ are given in Figure 2, depending on the distance. Dust concentration values were converted to mg/m^3 air.

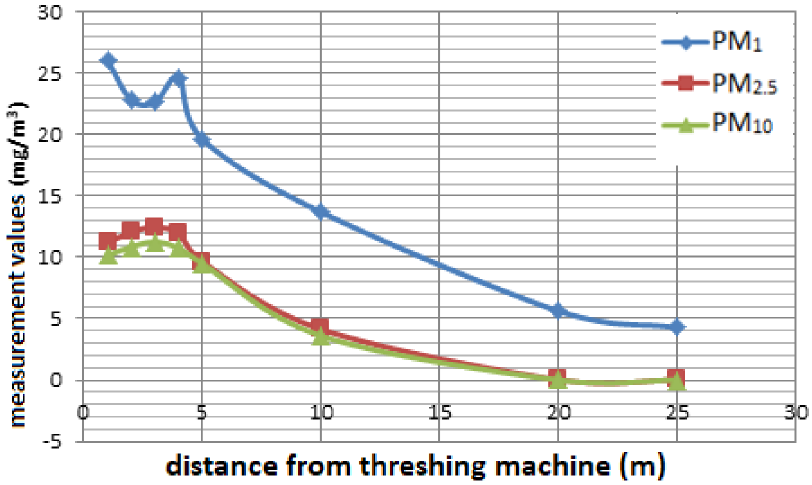

Figure 2. *Dust concentration values according to particulate matter size.*

The dust concentration values measured during the operation of the threshing machine were measured at the highest level at close and medium distances from the threshing machine. The dust concentration decreased for all three particle sizes as the study area expanded. This result can be explained by the natural precipitation of larger particles when the dust formed during the threshing process is accelerated [15]. Accordingly, the dust concentration in the working area before the machine started was below the threshold limit value according to ACGIH and WHO standards [8]. Therefore, the operation of the threshing machine was measured well above both the respirable threshold limit value and the total dust amount values.

When Figure 2 is examined, a significant decrease in dust concentration is observed after a distance of 5 meters (middle). While working with the threshing machine, the employees are at a maximum distance of 2 meters from the machine. At this distance, at all particle size sizes, dust concentrations were well above the 4 mg/m^3 threshold for both total dust and inhalation, according to the ACGIH and WHO. $PM_{2.5}$ and PM_{10} values fell below the respirable threshold values at 25 meters. However, the PM_1 dimension was not below the respirable threshold value according to ACGIH standards at any distance.

Dust concentrations from different sources should not exceed specific limit values to not adversely affect the health of the workers [3]. The air quality index prepared by the EPA is shown in Table 2. In the table, the effects of $PM_{2.5}$ particle size on human health are grouped according to the risk ratio. The dust concentration generated during working with the thresher was dangerous for human health according to the EPA air quality index for $PM_{2.5}$ size.

Table 2. *Particle size and air quality values for $PM_{2.5}$ (EPA,2013) [10, 18].*

Dust level $\mu g/m^3$	Air quality
0-50	**Well, little or no risk.**
51-100	**Moderate, acceptable.**
101-150	**Harmful for sensitive groups.**
151-200	**Harmful to health, seriously harmful for sentivite groups.**
201-300	**Healt alert. It is very harmful to healt for everyone.**
301-500	**Dangerous.**

The document 'Occupational exposure limits for hazardous substances workplace-Part 1: Chemical hazardous substances' states occupational exposure limits (OELs) for grain dust, while the American Conference of State Industrial Hygienists (ACGIH) states threshold limit values (TLVs) for grain powder [14]. In these standards, the maximum allowable concentration-time-weighted average (PCTWA) of free silica (< 10% of total dust concentration) is 4 mg/m^3 [15]. According to this, PM_1 of the clouds of dust generated during working with the threshing machine was at a density that would cause disease at all distances, while $PM_{2,5}$ and PM_{10} remained below the limit values that would cause disease at long distances.

In the total dust concentration, the PM_1 ratio was approximately 54%, the $PM_{2.5}$ ratio was approximately 23%, and the PM_{10} ratio was approximately 21% (Figure 3). Although the total respirable dust concentrations limit was not clearly defined, the PM_1 concentration exceeded the predicted upper limit. This can be explained by the fact that particles with diameters ranging from 0.1 to 1 μm have a longer life in the air and can be transported over long distances [16].

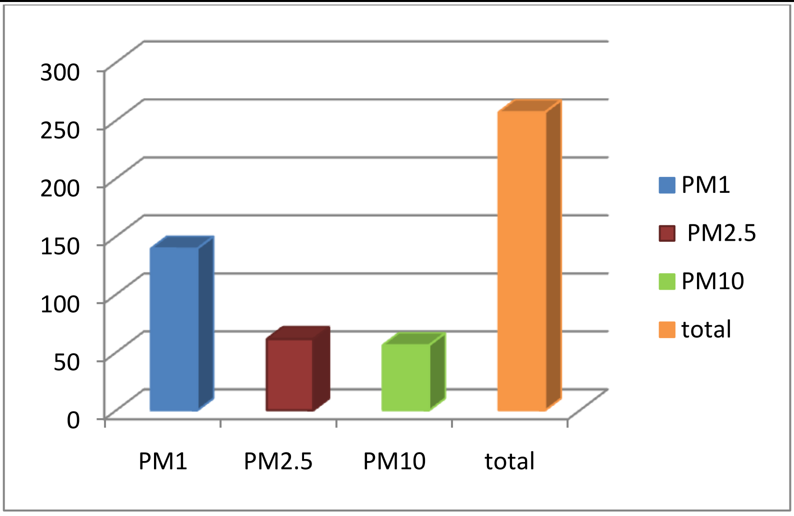

Figure 3. *Total dust concentration values according to particle size (mg/m^3)*

4. Conclusion

Dust produced in agricultural mechanization is a complex mixture that varies with season, climatic conditions, and type of agricultural production [11, 12]. In agricultural enterprises, many different business groups and depending on this, many different dust exposures occur, but there is no threshold value determined for each dust type in national and international organizations. In addition, for some organic dusts, mostly the total dust amount is given, and the respirable dust amounts or threshold limit values are uncertain. The total dust and respirable dust values of the threshing machines widely used in Turkey are uncertain, as no study has been done. In the dust control guide prepared by the Ministry of Labor and Social Security, there are no harvesting and threshing works among the workgroups for which dust masks are recommended depending on the particulate matter particle size in agriculture and livestock works [7].

1. Dust concentration emitted by the threshing machine can be reduced by spraying water on the dust outlets. In the study carried out in Italy to reduce the dust produced during the hazelnut harvest, a water reservoir was added next to the warehouse, and the water taken from there by a hose was sprayed into the dust outlets of the machine. While the dust emission values to which the operator was exposed were 8.8 mg/m^3 before spraying water, they decreased to 2.8 mg/m^3 after water spraying. The dust values measured in the harvested area decreased from 1.20 mg/m^3 to 0.30 mg/m^3 [16].
2. The amount of dust generated in the threshing process varies depending on the moisture content of the material. The dust level of the dry material is higher. Accordingly, to reduce dust exposure, the material should be blended with its moisture content (25%, y.b.) when harvested.
3. During the mechanized hazelnut harvest, together with the hazelnuts collected from the ground, dense foreign material (stone, soil, branch pieces, Etc.) enters the machine [4, 5]. Taking the harvested hazelnuts directly into the threshing machine without foreign material cleaning increases the dust concentration. Since cleaning the garden before harvesting will reduce the amount of foreign material collected from the ground by mechanical harvesting, there will also be a decrease in the amount of dust generated during the threshing process.
4. The use of filters at the dust outlets of the thresher can reduce dust exposure. However, studies are needed to select the appropriate filter. Studies have shown that filter performances are affected by particle type, aerodynamic particle diameter, and suspension time in the air [13]. In addition, factors such as filter cost, ease of use, and lifetime should be investigated.
5. At the end of the studies carried out with the hazelnut harvester, it was emphasized that the machine emits dust in a size that poses a danger to human health and that cyclone and cloth filters can be used to prevent this dust release [25].
6. Putting an electric hydraulic water spray pump at the dust outlets of the threshing machine can reduce the dust concentration by transmitting the resulting dust to the soil without mixing with the air [16].
7. The studies carried out are insufficient to identify dust originating from all agricultural works.
8. The threshing machine should be tested at different moisture contents, different engine speeds, and different mixing ratios, and possible results should be revealed.

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Development of mathematical model of plane-parallel movement of trailer harvesting machine

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Abstract. *This paper presents the basic principles of building a mathematical model of trailer harvesting, for which an example of a trailed combine harvester is considered. To develop this mathematical model, all the components are given, starting with the assembly of an equivalent scheme of plane-parallel movement of this harvesting unit, which consists of a wheeled aggregate tractor of classic layout and trailed behind the combine. And behind the combine is attached a cart for the harvest. Differential equations of relative motion of the collecting unit are compiled and solved on the basis of the Lagrange equation of the second kind.*

KEYWORDS*: BRUSHING CALCULATION, TRAILER HARVESTING MACHINE, DIFFERENTIAL EQUATIONS, GENERALIZED COORDINATES, GENERALIZED FORCES.*

1. Introduction

The main indicator of the quality of the technological process of harvesting is the loss. Thus, when harvesting cereals by combing plants at the root, the losses may be remains and not combing. Loss of remains depends on the regulation of the working bodies of the combing device and the kinematic mode of rotation of the combing drums. Losses without combing depend on the straightness and stability of the harvesting machine. If the trajectory of the harvesting machine deviates from straightness, significant grain losses occur due to non-combing. To ensure the stability of the movement of the harvesting machine, it is necessary to study its dynamics.

Fundamentals of stability of motion of a mechanical system are considered by Lyapunov A.M. in [1]. Further development of the theory of stability of motion was obtained in the works of Malkin I.G. [2] and Merkin D.R. [3]. Works by Vasilenko P.M. [4, 5] are devoted to the study of the dynamics and stability of the movement of trailer agricultural machines and units. The most complete questions of the dynamics of trailer units are studied in the works of Gyachev L.V. [6, 7]. Regarding the movement of collecting units, the issues of dynamics and stability of movement are considered in scientific works [8, 9, 10].

The purpose of this study is to compile the differential equations of motion of the harvesting machine in its plane-parallel motion and solve them in general for further use in determining the optimal parameters of this unit.

2. Results and Discussions

When conducting the study, we use a grain-harvesting machine-tractor unit of the combing type. So, consider the movement of the harvesting unit, consisting of a tractor MTZ-80, trailer harvester combing type and two-axle trailer-trolley 2PTS-4.0, which is used to collect the combed heap.

The harvesting unit is a three-link mechanical system, the portable movement of which is translational rectilinear. To simplify the analysis, we assume that the center of mass of the tractor in portable motion moves evenly, i e $V_0 = \text{const}$. The portable movement of the unit occurs together with the plane $X_1O_1Y_1$ Fig. 1 [8]. Under the influence of external factors (inequalities of the field surface), the links of the unit begin to produce relative motion.

The harvesting unit has five degrees of freedom. Thus, its relative motion will be determined by five generalized coordinates.

Consider each of them one by one. The tractor has two degrees of freedom in relative motion, so its position will be determined by two generalized coordinates.

Moving the center of mass of the tractor along the axis O_1X_1 will be determined by the generalized coordinate X_{S1}, rotation around the axis passing through the center of mass of the tractor – a generalized coordinate φ_1. Similarly, the rotation of the harvesting machine relative to the point of the trailer is denoted by the generalized coordinate φ_2.

The 2PTS-4.0 trailer is a two-link kinematic chain with two degrees of freedom. As generalized coordinates we take the angles of rotation φ_3 and φ_4 (Fig. 1).

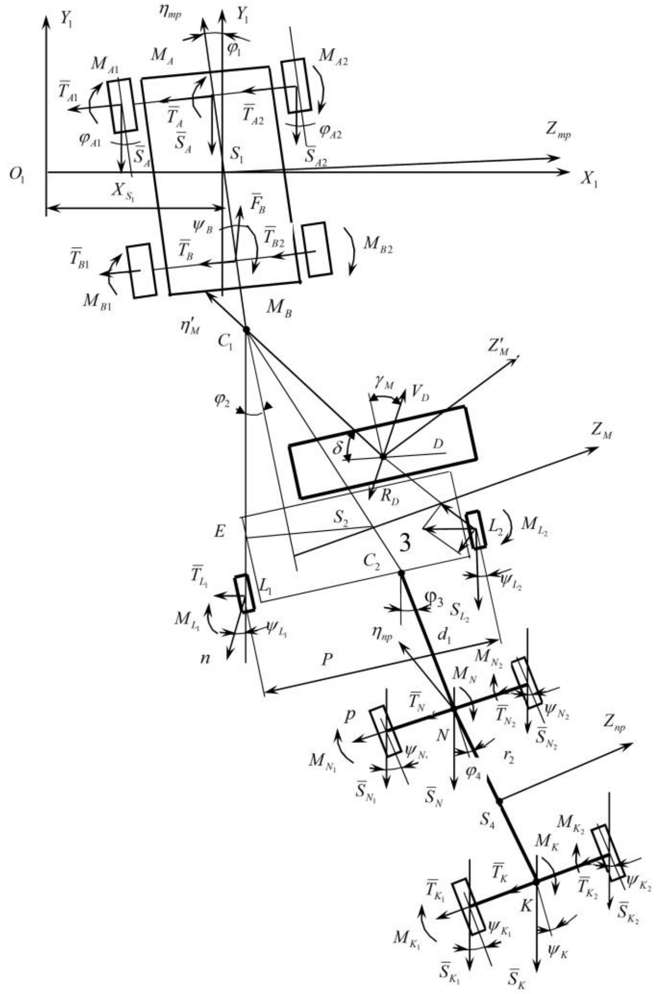

Figure 1. *Estimated scheme of the harvesting unit*

Consider the forces acting on the wheels of the unit.

Two groups of forces act on the wheels of the harvesting unit. The first group of forces acting on the wheels of the harvesting unit is the forces of elasticity of the tires arising from their transverse displacement ($\overline{T}_{A1}, \overline{T}_{A2}, \overline{T}_{B1}, \overline{T}_{B2}, \overline{T}_{L1}, \overline{T}_{L2}, \overline{T}_{N1}, \overline{T}_{N2}$), and the moments of elastic forces of the tires that occur when twisting each tire relative to the axis perpendicular to the surface of the field ($M_{A1}, M_{A2}, M_{B1}, M_{B2}, M_{L1}, M_{L2}, M_{N1}, M_{N2}, M_{K1}, M_{K2}$), (Fig. 1).

In fig. 1 marked: $\overline{T}_{A1}$ and $\overline{T}_{A2}$ – the elastic forces of the tires arising from the transverse displacement of the front wheels of the tractor relative to the bearing surface; $\overline{T}_{B1}$ and $\overline{T}_{B2}$ – the elastic forces of the tires arising from the transverse displacement of the rear wheels of the tractor relative to the bearing surface; $\overline{T}_{L1}$ and $\overline{T}_{L2}$ – forces of elasticity of the tires arising at cross shift of the left and right wheels of the harvesting machine concerning a basic surface; $\overline{T}_{N1}$ and $\overline{T}_{N2}$ – forces of elasticity of the tires arising at cross shift of forward wheels of the trailer 2PTS-4.0 concerning a bearing surface; M_{A1} and M_{A2} – moments of elastic forces of the tires of the front wheels of the tractor, which occur when twisting each tire relative to the axis perpendicular to the field surface; M_{B1} and M_{B2} – moments of forces of elasticity of tires of back wheels of a tractor arising at twisting of each tire concerning an axis of a perpendicular field surface; M_{L1} and M_{L2} – moments of forces of elasticity of tires of wheels of the harvesting machine arising at twisting of each tire concerning an axis of a perpendicular surface of a field; M_{N1} and M_{N2}; M_{K1} and M_{K2} – moments of elastic forces of the tires of the front and rear wheels of the trailer, which occur when twisting each tire relative to the axis perpendicular to the field surface.

The second group of forces acting on the wheels of the harvesting unit is the resistance forces to the unit moving over the field ($\overline{S}_{A1}, \overline{S}_{A2}, \overline{S}_{L1}, \overline{S}_{L2}, \overline{S}_{N1}, \overline{S}_{N2}, \overline{S}_{K1}, \overline{S}_{K2}$), (Fig. 1),

where: $\overline{S}_{A1}$ and $\overline{S}_{A2}$ – forces of resistance to rolling of front wheels of a tractor; $\overline{S}_{L1}$ and $\overline{S}_{L2}$ – forces of resistance to rolling of wheels of the harvesting machine; $\overline{S}_{N1}$ and $\overline{S}_{N2}$ – resistance forces to the rolling front wheels of the trailer; $\overline{S}_{K1}$ and $\overline{S}_{K2}$ – resistance forces to the rear wheels of the trailer.

In addition, there is another group of forces acting on the harvesting unit. These are the resistance forces arising during the operation of the computing device. Replace their action with the main vector $\overline{R}_D$, attached at the point D (Fig. 1).

To study the dynamics of a three-link aggregate, the problem of compiling differential equations of relative motion arises.

To do this, we use the original Lagrange equations of the second kind in generalized coordinates. Since the assembly unit has five degrees of freedom, using the recommendations [10] we will make five differential equations [9]:

$$\left.\begin{aligned}
&\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\varphi}_1}\right)-\frac{\partial T}{\partial \varphi_1}=Q_1;\\
&\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\varphi}_2}\right)-\frac{\partial T}{\partial \varphi_2}=Q_2;\\
&\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\varphi}_3}\right)-\frac{\partial T}{\partial \varphi_3}=Q_3;\\
&\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\varphi}_4}\right)-\frac{\partial T}{\partial \varphi_4}=Q_4;\\
&\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{x}_{S_1}}\right)-\frac{\partial T}{\partial x_{S_1}}=Q_5
\end{aligned}\right\}. \tag{1}$$

where T – kinetic energy of the harvesting unit; Q_1, Q_2, Q_3, Q_4, Q_5 – generalized forces; $\dot{\varphi}_1$, $\dot{\varphi}_2$, $\dot{\varphi}_3$, $\dot{\varphi}_4$, $\dot{x}_{S_1}$ – generalized speeds.

After determining the kinetic energy of the aggregate unit, generalized forces and substituting them in equation (1) we obtain a system of differential equations:

$$\begin{aligned}
&I_{S_1}\ddot{\varphi}_1+\ddot{X}_{S1}\cdot a\left(m_{у.м.}+m_{np}\right)+\ddot{\varphi}_1 a^2\left(m_{у.м.}+m_{np}\right)+\\
&+\ddot{\varphi}_2 abm_{у.м.}+\ddot{\varphi}_2 anm_{np}+\ddot{\varphi}_3 ad_1m_{np}+\ddot{\varphi}_4 ar_2m_{np}=\\
&=T_A\cdot h_1-T_B\cdot h_2-M_A-M_B+F_B\cdot\psi_B\cdot h_2-\\
&-2T_L\cdot a+2S_L\cdot a\cdot\left(\varphi_2-\varphi_1-\psi_L\right)+R\cdot a\cdot\left(\varphi_2-\varphi_1-\gamma_M\right)-\\
&-T_N\cdot a-T_K\cdot a+S_N\cdot a\cdot\left(\varphi_3-\varphi_1-\psi_N\right)+\\
&+S_K\cdot a\cdot\left(\varphi_3+\varphi_4-\varphi_1-\psi_K\right).
\end{aligned}$$

$$\begin{aligned}
&I_{S_2}\ddot{\varphi}_2+\ddot{X}_{S1}\cdot nm_{np}+\ddot{\varphi}_1 abm_{у.м.}+\ddot{\varphi}_1 anm_{np}+\\
&+\ddot{\varphi}_2 b^2m_{у.м.}+\ddot{\varphi}_2 n^2m_{np}+\ddot{\varphi}_3 nd_1m_{np}+\ddot{\varphi}_4 nr_2m_{np}=\\
&=-T_L\cdot l-S_L\cdot l\cdot\psi_L-M_L-T_N\cdot n\cdot\sqrt{1-\frac{r_1^2}{b^2}}-\\
&-T_K\cdot n\cdot\sqrt{1-\frac{r_1^2}{b^2}}-S_N\cdot n\cdot(\varphi_3-\varphi_2-\psi_N)\cdot\sqrt{1-\frac{r_1^2}{b^2}}-\\
&-S_K\cdot n\cdot\left(\varphi_3+\varphi_4-\varphi_2-\psi_K\right)\sqrt{1-\frac{r_1^2}{b^2}}-\\
&-S_L\left(l\cdot\psi_L\sin\left(\arccos\frac{p}{l}\right)+\left(p+l\varphi_2\right)\right)-\\
&-T_L\cdot l\cdot\sqrt{1-\frac{p^2}{l^2}}-R\cdot\gamma_M\cdot c.
\end{aligned} \tag{2}$$

$$\begin{aligned}
&I_{S_3}\ddot{\varphi}_3+\ddot{X}_{S1}\cdot d_1m_{np}+\ddot{\varphi}_1 ad_1m_{np}+\ddot{\varphi}_2 nd_1m_{np}+\ddot{\varphi}_3 d_1m_{np}=\\
&=-T_Nd_1-S_Nd_1\psi_N-T_Kd_1-M_N-S_Kd_1\psi_K.
\end{aligned}$$

$$\begin{aligned}
&I_{S_4}\ddot{\varphi}_4+\ddot{X}_{S1}\cdot r_2m_{np}+\ddot{\varphi}_1 ar_2m_{np}+\ddot{\varphi}_2 nr_2m_{np}=\\
&=-T_Kd_2-S_K\psi_Kd_2-M_K.
\end{aligned}$$

$$\begin{aligned}
&\ddot{X}_{S1}\left(m_{mp}+m_{у.м.}+m_{np}\right)+\ddot{\varphi}_1 a\left(m_{у.м.}+m_{np}\right)+\\
&+\ddot{\varphi}_2 bm_{у.м.}+\ddot{\varphi}_2 nm_{np}+\ddot{\varphi}_4 r_2m_{np}+\\
&+\ddot{\varphi}_3 d_1m_{np}=-T_A-T_B-2T_L-T_N-T_K+S_A\left(\varphi_1-\psi_A\right)+\\
&+2S_L\left(\varphi_2-\psi_L\right)+S_N\left(\varphi_3-\psi_N\right)-\\
&-\left(S_A+S_L+S_N+S_K+R_D\right)\left(\varphi_1-\psi_B\right)-R_D\cdot\gamma_y.
\end{aligned}$$

The resulting differential equations are quite cumbersome because the harvester is a complex dynamic system with five degrees of freedom, on which a fairly large number of forces and moments act. To simplify further analysis, consider the motion of the harvester separately, replacing the bindings by their reactions.

In relative motion, the harvesting machine performs plane-parallel motion with one degree of freedom. The following forces and moments of forces act on the harvesting machine (Fig. 2) [12]: $\overline{T}_{L_1}$ and $\overline{T}_{L_2}$ – elastic forces of the left and right wheels of the harvesting machine; M_{L_1} and M_{L_2} – moments of elastic forces of the tires of the left and right wheels of the harvesting machine; $\overline{S}_{L_1}$ and $\overline{S}_{L_2}$ – the resistance forces of the left and right wheels of the harvesting machine; $\overline{R}'_{C_1}$ – elm response with a tractor; $\overline{R}_{C_2}$ – the reaction of the elm with the trailer-cart to collect the combed heap; $\overline{R}_D$ – the main vector of eye resistance forces.

To compile the differential equation of motion of the harvesting machine, we use the Lagrange equation of the second kind in generalized coordinates [11]. As a generalized coordinate we take the angle φ_2 (Fig. 2):

$$\frac{d}{dt}\left[\frac{\partial T}{\partial \dot{\varphi}_2}\right]-\frac{\partial T}{\partial \varphi_2}=Q_3\,. \tag{3}$$

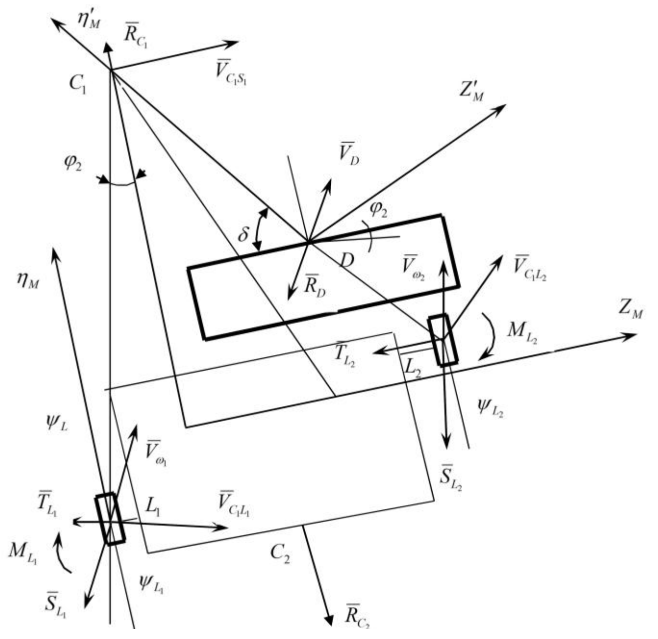

Figure 2. *Diagram of forces and moments of forces applied to the harvesting machine when replacing elms with their reactions*

Finally, we obtain the differential equation of the form [12]:

$$C_0 \cdot \dddot{\varphi}_2 + C_1 \cdot \ddot{\varphi}_2 + C_2 \cdot \dot{\varphi}_2 + C_3 \cdot \varphi_2 = 0; \tag{4}$$

where:

$$\begin{aligned} &C_0 = I_{C_1}; \\ &C_1 = \frac{R_D \cdot C_R^2}{V_0} + V_0 \cdot k_L \cdot I_{C_1}; \\ &C_2 = R_D \cdot C_R + R_{C_2} \cdot n - \ell \cdot L + R_D \cdot C_R^2 \cdot k_L; \\ &C_3 = -V_0 \cdot L + V_0 \cdot k_L \cdot R_{C_2} \cdot n + R_D \cdot C_R \cdot V_0 \cdot k_L \end{aligned} \tag{5}$$

Expressions (5) are the coefficients of the differential equation (4).

In the equations of expression (5) the following notations are accepted:

I_{C_1} – the moment of inertia of the harvesting machine relative to the point of its application to the tractor;

C_R – distance from the point C_1 hitching the machine to the tractor to the point D, application of the main vector of forces of resistance to combing;

n – the distance between the point of attachment C_1 of the machine to the tractor and the hitch point C_2 of the carts to the machine;

V_0 – the speed of the tractor that assembles the harvesting machine;

l – distance from the point C_1 of the attachment of the harvesting machine to the tractor to the wheel L_1;

k_L – coefficient of proportionality, which characterizes the elastic properties of the tires of the wheels of the harvesting machine;

L – designation determined from such an expression:

$$\begin{aligned} L = -C_L \cdot l - C_L \cdot l \cdot \sqrt{1 - \frac{p^2}{l^2}} - 2k_L \cdot f_L - S_L \cdot l \cdot k_L - \\ - S_L \cdot l \cdot k_L \cdot \sqrt{1 - \frac{p^2}{l^2}}; \end{aligned} \tag{6}$$

where C_L – tire stiffness coefficient, at displacement; f_L – torsional stiffness of the tire; p – the distance between the wheels of the harvesting machine.

To find the angle φ_2 of deviation of the harvester from the rectilinear trajectory, solve differential equations (4), for which we divide the left and right parts of equation (4) by the coefficient C_0, as known coefficient $C_0 = I_C$ (I_C – moment of inertia of the harvester relative to the point C_1), that is $C_0 \neq 0$:

$$\dddot{\varphi}_2 + \frac{C_1}{C_0} \cdot \ddot{\varphi}_2 + \frac{C_2}{C_0} \cdot \dot{\varphi}_2 + \frac{C_3}{C_0} \cdot \varphi_2 = 0\,. \tag{7}$$

The following should be noted:

$$\frac{C_1}{C_0} = a; \quad \frac{C_2}{C_0} = b; \quad \frac{C_3}{C_0} = c. \tag{8}$$

Then the differential equation (7) will look like:

$$\dddot{\varphi}_2 + a \cdot \ddot{\varphi}_2 + b \cdot \dot{\varphi}_2 + c \cdot \varphi_2 = 0\,. \tag{9}$$

Compose the characteristic equation:

$$n^3 + a \cdot n^2 + b \cdot n + c = 0\,. \tag{10}$$

As a result, a cubic equation was obtained. To solve it, we use the Cardano method [13], the essence of which is to reduce equation (10) to "incomplete form".

We introduce a substitution:

$$n = k - \frac{a}{3}\,;$$

$$\left(k - \frac{a}{3}\right)^3 + a \cdot \left(k - \frac{a}{3}\right)^2 + b \cdot \left(k - \frac{a}{3}\right) + c = 0\,. \tag{11}$$

Perform algebraic transformations and then obtain the equation:

$$k^3 + k \cdot \left(-\frac{a^2}{3} + b\right) + \left[2 \cdot \left(\frac{a}{3}\right)^3 - \frac{a \cdot b}{3} + c\right] = 0\,. \tag{12}$$

Denote:

$$-\frac{a^2}{3} + b = f\;; \quad 2 \cdot \left(\frac{a}{3}\right)^3 - \frac{a \cdot b}{3} + c = \eta\,. \tag{13}$$

In the final form, an incomplete cubic equation is obtained:

$$k^3 + k \cdot f + \eta = 0\,. \tag{14}$$

The roots of the incomplete cubic equation are equal to [14]:

$$\begin{aligned} &k_1 = A + B\,; \quad k_2 = -\frac{A + B}{2} + i \cdot \left(\frac{A - B}{2} \cdot \sqrt{3}\right); \\ &k_3 = -\frac{A + B}{2} - i \cdot \left(\frac{A - B}{2} \cdot \sqrt{3}\right), \end{aligned} \tag{15}$$

$$\text{where } A = \sqrt[3]{-\frac{\eta}{2} + \sqrt{Q}}\;; \quad B = \sqrt[3]{-\frac{\eta}{2} - \sqrt{Q}}\,. \tag{16}$$

In turn:

$$Q = \left(\frac{f}{3}\right)^3 + \left(\frac{\eta}{2}\right)^2. \tag{17}$$

Thus, obtained as a result of solving the cubic equation (14), we have one real root and two complexly conjugate roots. Then the general solution of differential equation (9) will look like [15, 16]:

$$\begin{aligned} &\varphi = C_1 \cdot e \cdot \frac{A + B}{2} \cdot t + e \cdot \left(-\frac{A + B}{2} \cdot t\right) \times \\ &\times \left[C_2 \cdot \cos\left(\frac{A + B}{2} \cdot \sqrt{3}\right) \cdot t + C_3 \cdot \sin\left(\frac{A + B}{2} \cdot \sqrt{3}\right) \cdot t\right], \end{aligned} \tag{18}$$

where C_1, C_2, C_3 – integration steels, which are determined from the initial conditions.

Thus, the solution of the differential equation of relative motion of this harvesting unit is obtained. Using this solution, it is possible in the future with the help of PC to investigate the plane-parallel motion of the specified unit to determine the optimal construction and kinematic parameters.

4. Conclusion

As a result of the analytical studies, a new mathematical model of the relative motion of the trailed harvesting machine was constructed. To consider the specified motion of the harvesting machine, its equivalent scheme was initially constructed. Using the output Lagrangian equations of type II, the differential equation of relative motion of the given harvester and tractor unit was compiled and solved.

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Ways to grow the efficiency of the harvesting and transport technological machine complex for grain crops

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Abstract: *The article provides a rationale for an improved technological process for transporting grain from combine harvesters (GH) by a semitrailer-dump truck (STT), combined for field work with a tractor and a saddle trailer. As a result of the analysis, it was found that the minimum specific duration of harvesting and transport operations in the field is achieved when using a semi-trailer with a tractor to work with minimal time spent on the formation of transport units using a semi-automatic fifth wheel coupling.*

We offer a technical solution, which consists in the temporary redistribution of the grain mass in the back of the STT during its transportation in the field. At the same time, the rear wheels of the STT are partially unloaded and do not compact the soil, and the saddle trailer, equipped with wide-profile low-pressure tires, takes on additional load without significant soil compaction.

The use of STTs operating by the semi-shuttle method in two parts: in the field and on the road section, increases the productivity of the harvesting and transport complex in 1.5 times.

Keywords*: GRAIN TRANSPORTATION, COMBINE HARVESTERS, SEMITRAILER MOVEMENT, SEMI-TRAILER TIPPER, TRAILING SEMI-TRAILER, PRODUCTIVITY.*

Anotation. The article substantiates the advanced technological process of grain transportation from grain harvesters (GH) by a semi-trailer dump truck (STT) with a tractor and a truck trailer (TT). One of the main reserves for increasing the productivity of the combine is to increase the utilization of its time of change through the use of reloading technology based on interoperable compensators - tractor loaders (PP) brands PBN-30, PBN-40, PBN-50, Kinze 850 and others, and trucks. The disadvantage of this technology is the significant downtime of vehicles.

A comparative analysis of different technological schemes of harvester work and vehicles showed that the minimum specific duration of harvesting and transport operations is achieved when using the STT with a tractor to work in the field with minimal time spent on the formation of transport units using a semi-automatic fifth wheel coupling. STTs are used as reversible, which allows to organize continuous operation of tractors in the areas "GH - field edge" and "field edge - grain receiving point (GRP)", where possible downtime TT is replaced by downtime only STT, which if necessary complement technological units.

We have proposed a technical solution that contains a temporary redistribution of the mass of grain in the body of the STT by loading it into the front of the body. At the same time, the rear wheels of the STT are partially unloaded and do not over-compact the soil, and the trailer mounted trailer, equipped with wide-profile low-pressure tires, absorbs additional load without significant soil compaction.

Theoretical analysis of the rhythm of grain movement by individual technological units of the harvesting and transport complex allowed to determine the analytical dependences of the main parameters of these units on the productivity of the SC and the volume of its hopper, nominal capacity of the STT, duration of the use of semi-shuttle STTs in two parts: in the field and on the road, increases productivity (average production) of TT by 1.5 times, as well as eliminates the cost of specialized trailers, reloaders and double grain overload.

Formulation of the problem

Introduction into the technological line between combine harvesters and vehicles during the harvesting of the intermediate link - interoperational compensator can significantly, compared to direct road transport of grain, reduce the time of harvesting and transport operations and generally increase the efficiency of the harvesting complex. LC while waiting for grain to be unloaded from the hopper.

The role of such mobile compensators is performed by specialized tractor trailers-reloaders (PP), another name - reloading storage bunkers - PBN, PNB with screw devices for unloading, as well as automobile and tractor universal trailers and semi-trailers [1, 2] (Fig. 1).

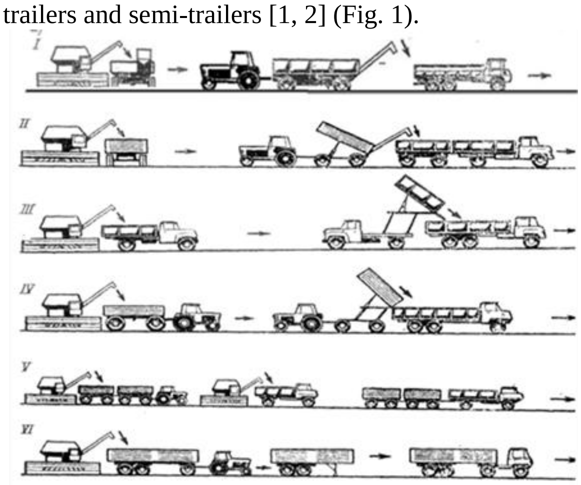

Fig. 1. *Schemes of grain transportation from combines with the use of mobile interoperative compensators:*
I-II - specialized tractor trailers-loaders; III - IV - dump trucks and tractor trailers with pre-lifting of the body; V-VI - tractor trailers and semi-trailers with rolling trailers

The increase in the productivity of GHs is due to the reduction of their downtime to wait for the unloading of bunkers. The use of PP with wide-profile low-pressure tires reduces soil compaction and prevents heavy trucks from entering the field. The analysis of the technological scheme of grain transportation from combines with the use of PP permits also reveals a number of shortcomings that prevent the achievement of the maximum effect, which include the following:

- the need for timely access of the JSC to the PP causes downtime TT (up to 30% of the time of change [3]);
- the need for additional operations (compared to the technology of direct transport) - reloading of grain from one

vehicle (trailer-reloader) to another (heavy-duty JSC). Such overloading of grain with the use of screw working bodies requires additional energy, time and does not exclude mechanical damage to the grain.

Analysis of recent research

In order to find rational schemes for transporting crop products from combines, we used data from the analysis of compensators [2]. Since it is possible to use vehicles (vehicles) of different loads for grain transportation, it is expedient to determine the specific duration of harvesting and transport operations (SDO) for comparative evaluation, which is attributed to 1 ton of transported grain. In fig. Figure 2 presents the obtained dependences of SDO on the load capacity of the vehicle. The introduction of an intermediate link in the technological line between combines and road vehicles allows to significantly (2-3 times) reduce the duration of the SDO compared to direct road transport.

Production implementation of scheme VI with a minimum specific duration of SDO can be achieved by eliminating soil compaction by the wheels of the STT and due to the rational time spent on uncoupling-coupling of the STT. The semi-trailer in combination with a tractor can perform the function of a mobile compensator - instead of trailers PBN-30, PBN-40, Kinze 850 and others, which will eliminate the cost of purchasing specialized equipment.

At the same time, the vehicles are used as circulating STT, which allows to organize the continuous operation of tractors on the site "Field edge - GRP", where possible downtime TT are replaced by downtime only STT, which, if necessary, complement the technological units.

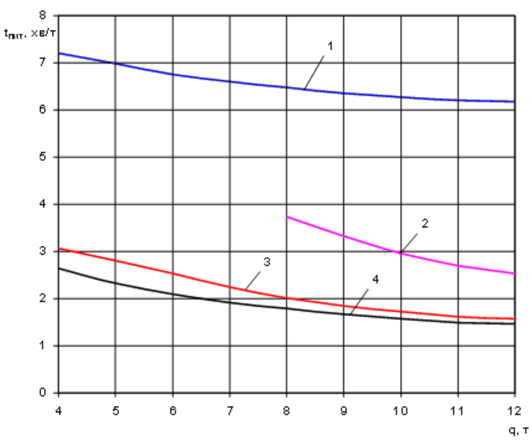

Fig. 2. Dependence of the specific duration of collection and transport operations on the load of vehicles for different technological schemes: 1 - direct road transport; 2 - transportation according to scheme V; 3 - transportation under schemes I, II, III, IV; 4 - transportation according to scheme VI.

The purpose of research

The aim of the research is to increase the efficiency of the transport and production process during grain harvesting by using a dump semi-trailer as an interoperative compensator in combination with a tractor for field work and with a car or tractor for road transport. To achieve this goal it is necessary to solve the following tasks: 1) to conduct a theoretical analysis of the transport and production process during grain harvesting with some improvement, 2) to calculate the parameters of harvester-transport machine complex (HTC) according to the analysis data.

Research results

Taking into account the positive evaluation indicators and the availability of certain technical support, which allows to reduce the duration of uncoupling-coupling of the semi-trailer from tractors, we adopted for further research scheme VI with some improvement.

XTC contains a group of GHs and tractor trains (Fig. 3), which includes a tractor, semi-trailer and trailer PSP-20 (Fig. 4,5).

Fig. 3 *Scheme of a tractor road train with PSP-20*

Saddle trailer PSP-20 (table 1), which connects the tractor (tractor) and the state of the train, equipped with a special hitch (SZP), also contains a drawbar for connection to the tractor and running gear, provides the ability to rotate the semi-trailer relative to the tractor around the axis of the coupling pin in the horizontal plane.

Fig. 4. *PSP-20 saddle trailer*

Таблиця 1.Технічна характеристика ПСП-20

Length, mm	4 900
Width, mm	2 400
Height, mm	1 150
Saddle height (regulated hydraulic cylinders), mm	1 250 - 1 400
Maximum load on the saddle, kg	20 000

Semi-trailers with tractors are used consistently in two technological links: for work in the field "GH - STT - tractor" and for transportation on the road from the field to GPR - "STT - road tractor (TT - car or tractor)" (Fig.5, 6). In the first link, the STT functions as an interoperable compensator, which is loaded with grain from the hoppers of at least two combines.

After filling with grain, the STT is transported to the edge of the field, uncoupled and replaced with an empty one for further work in the field, and loaded STTs are transported by road tractors to GRP, where they are unloaded and returned empty to the field edge. The use of a trailer with special semi-automatic hitch (SH) allows to reduce the duration of time for hitching (uncoupling - coupling) STT.

In order to reduce soil compaction, we have proposed such a technical solution that contains a temporary redistribution of the mass of grain in the body of the semi-trailer during its transportation to field [4]. Taking into account the fact (to see fig. 3) that the STT body has two generalized wheel bearings on the soil: a rear three (two) axle bogie and the front two-axle in the form of a rolling semi-trailer PSP-20, which is equipped with wide-profile low-pressure tires, it is advisable to load grain from the combine bunker into the front part of the semi-trailer body.

Fig. 5. *NPS 3250 grain truck semi-trailer with PSP-20 saddle trailer for work with a tractor in the field*

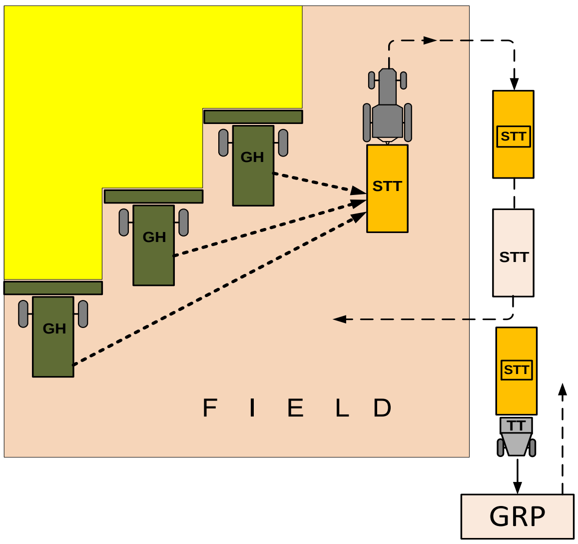

Fig. 6. *Technological scheme of grain loading from combines and transportation with the use of state of emergency: GH - combine harvester; STT - semi-trailer (empty and loaded); TT - truck or tractor; GRP is a grain receiving point.*

This creates such a distribution of pressure on the ground when the tractor road train with PSP-20 moves across the field, in which the rear wheels of the STT will be partially unloaded and do not compact the soil, and the rolling saddle trailer takes on additional load and, thanks to wide-profile low-pressure tires, does not significantly compact the soil. According to preliminary calculations when using a semi-trailer NPS 3250 grain truck with a capacity of 25 tons (board height 2.1 m, body length 6.3 m) loading grain into the front of the body can reduce the load on the rear wheels to 5 tons with loading SPS-20 up to 20 tons.

After transportation to the edge of the field and hitching for transportation on the road, the body of the STT with the help of a hydraulic cylinder is tilted to the horizon for uniform distribution of grain under the action of gravity on the bottom of the body. The technical result provided by the above set of features is to reduce the pressure on the ground of the rear wheels to the allowable agricultural requirements.

To calculate the operating parameters of HTC in [1] considered the rhythm of the first technological link: "GH - semi-trailer dump truck with tractor" and determined the number STT $n_{П1}$, which serve a group of combines m_K according to the formula:

$$n_{П1} = CEILING\frac{m_K}{m_{KH}}, \text{units} \qquad (1)$$

where CEILING is a function that returns the nearest larger integer value;

m_K - total number of combines in the group;

m_{KH} - the number of combines serviced by one of STT.

To determine the number of GHs served by the semi-trailer, the technological chain of interaction of GHs and STTs is considered. After loading the first grain hopper from the GH, the STT moves in turn to the next combines serviced by it, loads with grain, goes to the edge of the field, uncouples the STT and attaches an empty STT and returns to the first unloaded GH for the next loading. The number of units of m_{KH} combines serviced by one STT is defined as [1, 5]:

$$m_{KH} = INT(\omega_K d_B(\frac{9,25}{W_{KP}} + \frac{8,33}{W_{ШK}}) - 8,33t_{BП} - 0,667)$$

units, (2)

where INT is the function that returns the nearest least integer value;

W_{KP} - productivity of GH for 1 hour of the main time of its work, t / h;

$W_{ШK}$ - productivity of the unloading auger GH for 1 hour of the basic time, t / h;

$t_{B-П}$ - average duration of hopping (uncoupling - coupling) STT;

ω_K — volume of the combine hopper, m^3;

$d_в$ — volume mass of grain, t / m3.

On the basis of this equation, the graphical dependence of m_{KH} on W_{KP} and ω_K is constructed (Fig. 7).

The analysis of the given dependences shows that the capacity of the bunker of GH is the essential factor influencing quantity of grain loaded for one working cycle in STT. The number of m_{KH} combines serviced by one STT increases due to the increase in the volume of GH bunkers. Thus, the amount of GH with W_{KP} = 9.5 t / h, which can be serviced by one STT, increases from 1 to 6 units with increasing bunker capacity from 3 to 11 m^3. For GHs with a constant hopper volume, an increase in m_{KH} is achieved while decreasing the W_{KP} performance.

The choice of loading capacity of STT is carried out, proceeding from a condition of multiplicity of loading capacity of a body of STT and the bunker of GH:

$$q_H \geq q_Б \rho_T, \quad (3)$$

where q_H - the rated capacity of the selected state of STT; ρ - the number of bunkers GH, which will fit in the body of the STT;

$q_Б$ - the mass of grain contained in the hopper GH.

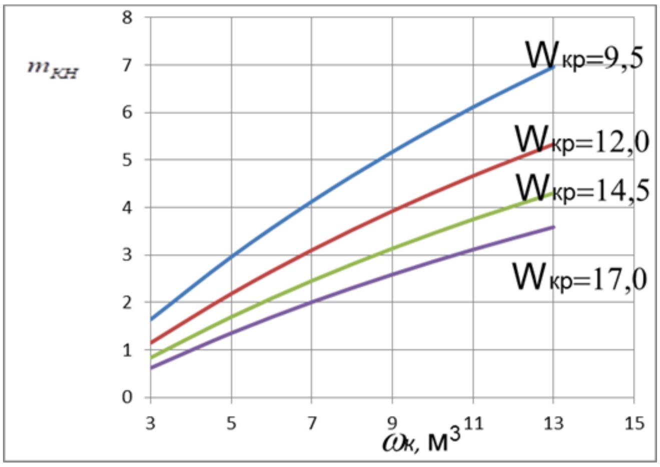

Fig. 7 *- Dependence of the number of m_{KH} combines, which are serviced by one STT, on the capacity of the bunker GH for a certain productivity W_{KP} = 9.5; 12.0; 14.5 and 17 t / h.*

The second condition for choosing the brand of STT: the capacity of the body of the selected STT must be a multiple of the capacity of the combine

$$\omega_H \geq \omega_K \rho. \quad (4)$$

Based on expressions (2-4), choose the appropriate load capacity brand of STT.

The total rational amount of GH that works in a particular HTC is defined as

$$m_K = m_{KH} \cdot n_{П1} \text{ units.}, \quad (5)$$

where $n_{П1}$ - the number of STT with a tractor in HTC.

The current condition of the second link "STT - TT" is considered by us and it has the following form:

$$R_2 = I_2, \quad (6)$$

where R_2 - the working rhythm of the STTs with tractors, hours; I_2 - interval of coming, hours.

The rhythm of work of the group of STT with tractors in the field is

$$R_2 = \frac{0{,}08 + 0{,}12\rho + 2t_{В-П}}{n_{П1}} \text{ h.} \quad (7)$$

TT coming interval:

$$I_2 = \frac{t_{ОБ}}{n_{AT}} = \frac{2t_{В-П} + \frac{2l_{ij}}{v_T} + t_{ВИВ}}{n_{AT}}, \text{ год.}, \quad (8)$$

where $t_{ОБ} = 2t_{В-П} + \frac{2l_{ij}}{v_T} + t_{ВИВ}$ - the duration of the turnover of TT, hours; n_{AT} - number of truck tractors, units;

$t_{ВИВ}$ — the duration of the STT at the unloading point, depending on the level of mechanization and organization of work, hours;

lij - the distance of grain transportation from the field (point i) to the point of unloading GRP (point j), km;

v_T — average technical speed of TT.

After substituting the values from (7 and 8) to (6) and the corresponding transformation, we obtain the number of tractors for transporting grain in GRP from the equation:

$$n_{AT} = CEILING \frac{n_{П1}(2t_{В-П} + \frac{2l_{ij}}{v_T} + t_{ВИВ})}{0{,}08 + 0{,}12\rho + t_{В-П}} \text{ units.} \quad (9)$$

The total number of STTs required for the operation of HTC (moving, waiting to be hitched and under load) is equal to the number of STTs operating in both links and is determined by the formula [2]:

$$П = n_{П1} + n_{AT} + n_З \text{ units,} \quad (10)$$

where $n_З$ - the additional number of STT, which takes into account the stochasticity of their movement on the road and is necessary for use during accidental delay of TT. This amount is determined experimentally during the operation of HTC and is placed on the edge of the field.

To quantify the transportation of grain from the field, we use the indicator of productivity of vehicles for the working day

$$W_{WД} = \frac{Q_{WД} \cdot l_{ij}}{n_{TT}} \text{ t·km/working day}, \quad (11)$$

where - $Q_{WД}$ the amount of grain that is collected and transported by the harvesting and transport complex for 1 working day.

Thus, on the basis of the theoretical analysis of the work of the harvesting and transport complex of machines with circulating semi-trailers dump trucks, the method of determining the composition of HTC is substantiated.

Let's compare this variant of grain harvesting and transportation technology with the most advanced in terms of the pace of implementation in Ukraine reloading technology with the use of reloading trailers in the following example. Consider the application of technological schemes for harvesting grain from an area of 2100 ha by John Deere 9780 combine harvesters and grain transportation to the receiving point (W_{KP} = 15.3 t / h,, d_B = 0.75 t / m3, yield U = 6 t / ha, number of working days for harvesting grain according to agricultural requirements D_W = 10 days, shift duration is 8 hours, coefficient of variability of shift K_S = 1.5, distance of grain transportation lij = 8 km, v_T = 40 km / h), transport composition is shown in table 2.

Calculations of parameters for the technology with the use of STT were carried out in accordance with the methodology presented in this paper. For reloading technology, the calculations were performed according to the methodology contained in [1]. The results of the calculations are presented in table 2.

Calculations of parameters for the technology with the use of NP were carried out in accordance with the methodology presented in this paper. For reloading technology, the calculations were performed according to the methodology contained in [1]. The results of the calculations are presented in table 2.

From the presented data it is seen that the use of STT, which work on semi-shuttle traffic in two parts: in the field and on the road, provides an increase in productivity (average output) TT 1.5 times from 210 to 315 t / working day by reducing their downtime. This allows to reduce their quantitative composition in HTC accordingly.

Table 2. Comparative technical-operational and quantitative indicators of HTC work

Technological options	Machines of the harvesting and transport complex							Average production of one TT, t/working. day.
	GH John Deere 9780	ПП Кінзе 850	STT NP grain truck 3250	John Deere 8440 tractor	Iveco Trakker AT260T44 tractor	KamAZ 6520 AGRO	PSP-20 saddle trailer	
Reloading technological scheme	9	3	-	3	-	6	-	210
Transportation by semi-trailers	9	-	7	3	4	-	3	315

Conclusions

1. Temporary redistribution of grain mass in body NP during its transportation in the field by a tractor and application of the PSP-20 saddle trailer with wide-profile low-pressure tires allows to reduce soil compaction.

2. Improvement of technological process of grain transportation from combines by semi-trailers by dump trucks is substantiated and the corresponding technique of definition of rational parameters of a complex at application in the field of saddle trailers PSP-20 is specified. The use of semi-shuttle vehicles in two links: in the field and on the road, provides an increase in productivity (average production) of blood pressure by 1.5 times from 210 to 315 t / rd. by reducing their downtime, which allows to reduce their number in the ZTK.

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Study of grinding corn stalks by a roller grinder with different knives positioning

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Abstract: *The work is devoted to the study of the efficiency of the technological process of grinding corn stalks with a roller-grinder. Developed and manufactured roller-shredder, the design of which provides for the possibility of direct (left) and inverted at 1800 (right) installation of the cutting edge of the knives relative to their direction of rotation.*

It was noted that in the range of less than 50 mm the percentage of crushed stems in the cat with the right location of the knives was 20% higher than with the left layout of the knives. The total value of the percentage of crushed stem particles in the range of 0-100 mm for the right was 83.6%, for the left 81.9%. In the range of 101-150 mm the share of crushed stems in the roller with the left arrangement of knives was 11.0%, with the right 7.7%, in the range of 151-200 mm, respectively, 4.6% with the left, and 6.0% with the right, in the range over 201 mm, with the left 2.6%, with the right 3.1%.

The average relative to the total weight percentage of crushed stem particles from the total weight of the fraction was for the range 0-50 mm - 20.3% for the right and 12.8% for the left, the range 51-100 mm - 23.8% for the right and 31.3 % for the left, range 101-150 - 14.8% for the right and 18.2% for the left, range 151-200 mm - 24.1% for the right and 16.8% for the left, in the range over 200 mm - 4 , 7% for the right and 20.9% for the left, respectively.

KEYWORDS: *GRINDING OF CORN STALKS, PLANT REMAINS, ROLLER-SHREDDER, INDICATORS OF QUALITY OF GRINDING*

1. Introduction

The technological operation of grinding and wrapping plant residues is extremely important. This issue is especially relevant when harvesting coarse-stemmed crops, such as corn, sunflower, hemp, canola, green manure and a number of other crops. Under the conditions of timely performance of the operation it is possible to accumulate sufficient moisture in the soil, while creating a nutrient medium for biological processes. Marked operations of grinding and wrapping of stem particles are carried out by special machines. The most common among them are combined units containing a disc harrow and a roller-shredder. Under the conditions of application of such machines the agronomic indicators of uniformity of mixing of the crushed particles of stalks with soil improve, favorable conditions for crops are created.

Growing corn requires extra effort to control the corn borer. The spread of this pest is gaining a threatening rate for culture. Chemicals alone are not enough to solve the problem. Effective pest control results can be achieved by using crop residue shredders. Shredded corn stalk to a size of less than 50 mm makes it impossible for the butterfly to overwinter.

Note the relevance of research aimed at developing special machines that contain rollers. The use of rollers in combined units allows rapid surface tillage with intensive mixing, stubble peeling, cultivation of corn, sunflower, rapeseed fields with a large number of crop residues, pre-sowing tillage and organic wrapping.

2. Preconditions and means for resolving the problem

Note the existence of significant differences in the methodologies of substantiation of rational technological parameters of rollers. This largely applies to both roller shredders used in the mono gun version, and in combined machines.

Fluctuations in a wide range of mechanical and technological properties of the plant environment are among the main factors that determine the quality of work of means for grinding.

Modern tillage systems are based on the analysis of biological characteristics of crops, field condition, agrophysical properties of soils, climatic, organizational, technical, technological and production capabilities of the economy [1].

The most common tillage systems include basic tillage with pre-stubble peeling and appropriate measures of pre-sowing and post-sowing soil preparation [2].

Among the main operations of loosening the topsoil to preserve existing moisture reserves, complete pruning and mechanical destruction of perennial and annual weeds, shallow wrapping of weed seeds in the soil, grinding of rhizomes of wheat and thistle roots, mechanical destruction of pathogens and pests [3].

Stubble peeling is carried out in the next operation after harvesting the predecessor. Such actions contribute to the maximum preservation of soil moisture. This makes it possible to cultivate the field efficiently, without blocks [4].

It should be noted that in the above publications there is no quantitative assessment of the quality of performance of operations of crushing coarse-stemmed crops in the entire range of plant residue sizes.

The article [5] presents the results of research of the machine-tractor unit, which simultaneously performs technological operations of grinding and soil wrapping of plant residues (sunflower stubble). The first operation is performed thanks to the shredder of plant residues, installed in front. The plow installed behind carries out operation of wrapping. However, the issue of determining the impact on the quality of grinding of plant residues of the speed of the unit remained out of the authors' attention.

The machine developed by the authors of the article [6] combined the functions of stubble cleaning and furrow opening. According to the results of statistical analysis, it was concluded that the speed of rotation of the blade, which destroys the stubble, did not affect the resistance of tillage. However, the authors did not pay attention to the issue of determining the influence of the location of the cutting edge of the knife on the quality of grinding sunflower stalks.

According to the results of experimental studies of a two-roller cultivator, the high quality of its work on grinding corn stalks was noted [7]. The rate of shredding of stems reached 90%. However, the authors do not give specific values of the degree of grinding of corn stalks in the ranges 0-50mm, 50-100mm, 100-150mm, 150-200mm, more than 200mm.

The authors of the article [8] on the basis of the developed mathematical model analyzed the conditions of interaction of the stem with the opener. Two types of possible options for the location of knives are proposed, which creates the preconditions for the design of a new type of narrow-band rotary cultivators and shredders of plant residues. However, the authors did not pay attention to the experimental study of the proposed design.

Note the relevance of the development of special machines that contain rollers. Thanks to them, it is possible to quickly perform surface tillage with intensive mixing, stubble peeling, cultivation of fields with a large number of residues of coarse-stemmed crops, pre-sowing tillage and wrapping of organic fertilizers.

3. Purpose of the study

The work is devoted to the study of the efficiency of the technological process of grinding corn stalks with a roller-grinder. Such actions are consistent with the development of systems of measures aimed at combating pests and diseases of culture. The most dangerous are corn butterfly.

The results of this publication are systematically consistent with the work previously conducted and published by the authors [9].

The aim of the research is to increase the efficiency of grinding and wrapping in the soil particles of corn stalks by establishing the quality of grinding with a roller-grinder depending on the location of the cutting edge of his knives. This will enable more effective ways to control pests and diseases of corn, reduce uneven grinding and energy costs, intensify the grinding process.

To achieve this goal, the following tasks were set:

- to investigate the influence of the location of the cutting edge of the knife of the roller-shredder on the quality of the operations of grinding corn stalks;
- to investigate indicators of quality of performance of operations of crushing and wrapping of corn stalks by the combined unit as a part of a disk harrow with a roller-shredder depending on the scheme of an arrangement of a cutting edge of its knives.

4. Results and Discussion

Previous studies have presented the results of the development and manufacture of a prototype roller-shredder, as well as to determine the impact of the location of the cutting edge of the roller blade on the quality of shredding of sunflower stalks [9]. Developed and manufactured roller-shredder, the design of which provides for the possibility of direct (left) and inverted to 1800 (right) installation of the cutting edge of the knives relative to their direction of rotation.

In accordance with the program of complex research aimed at solving the important problem of increasing the efficiency of production of coarse-stemmed crops, a prototype of a combined unit based on a heavy disc harrow was developed and manufactured. The main difference of the above unit is the use of a variable module - a roller-shredder, which allows you to intensify the process of grinding and wrapping to a depth of 25 cm coarse plant residues.

The structural and functional scheme of the combined unit, containing the roller-shredder in combination with the disc harrow BDVP-3,8, is shown in Fig.1.

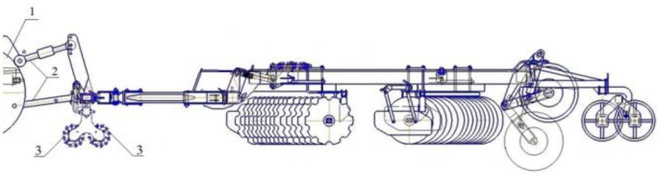


Fig. 1. *- Scheme (side view) of a disc harrow with a roller-shredder for additional grinding of plant residues: 1 - energy means; 2 - coupling device; 3 - knives of a cat-shredder*

The experimental sample of the combined unit (Fig. 2) for tillage and mulching of the soil with crop residues of corn was studied in the conditions of the research sites of SE "Olenivske" NSC "IMESG" (Kyiv region).

Fig. 2. *- Experimental sample of the combined unit for cultivation and mulching of the soil with plant remains*

According to the research program, a single pass was carried out by the combined unit on the agricultural background, which was a flat area of the field after harvesting corn for silage. In the process of research, the indicators of grinding and wrapping of plant remains in the soil were determined by an experimental combined unit.

The experimental sample of the combined unit for tillage and mulching the soil with plant residues was aggregated with T-150K energy. The speed of movement of the unit in all experiments was 7.2 km / h.

The program of experimental researches provided research of indicators of quality of performance of technological operation of crushing and wrapping in soil of stalks of corn:

- roller-shredder with the right scheme of knives;
- a roller-shredder with the left scheme of an arrangement of knives;
- the combined unit containing the roller-shredder with the right scheme of an arrangement of knives;
- the combined unit containing the roller-shredder with the left scheme of an arrangement of knives.

Processing the results of experimental studies according to [10]. The number of crushed stem particles that fall into the established size ranges characterizes the frequency of occurrence in each interval. The grouping of data smoothes out random oscillations of crushed stem particles, which are not characteristic of a large amount of data, preserves the main, characteristic features of the collected experimental material as a whole. The selected number and values of group intervals prevent significant loss of information about the process and do not distort it. In our case, the experimental data were grouped at intervals of the same size, which was due to the method of selection of crushed stem particles.

Note that the total number of shredded remnants of corn stalks roller-shredder was determined by recalculating the total number of shredded stalks, which was collected on the soil surface. The average value of the collected crushed particles was 312 pieces. at an average weight of 414g.

The distribution of crushed corn stalks by the length of the fractions is shown in Fig. 3.

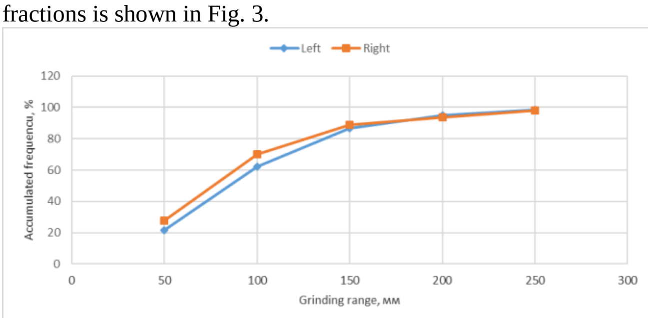


Fig. 3. *- Distribution of crushed stalks of corn crop residues by length of fractions at a speed of 7.2 km / h*

Note that in the range less than 50 mm. the percentage of crushed stalks with the right location of the knives exceeded that of the roller with the left location of the knives by 20%. The total value of the percentage of crushed stem particles in the range of 0-100 mm for the right was 83.58%, for the left 81.89%. In the range of 101-150 mm the share of crushed stalks in the roller with the left arrangement of knives was 10.97%, with the right 7.69%, in the range of 151-200 mm, respectively, 4.59% with the left, and 6.04% with the right, in the range over 201 mm, with the left 2.56%, with the right 3.07%.

Note the excess in the range of 0-50 mm of the average weight of the stem particles in the results with the right location of the knives above the left scheme. This excess of the average weight was, for one sample, the proportion of stems 0.042 g, or 10%.

The average relative to the total weight percentage of crushed stem particles from the total weight of the fraction was for the range 0-50 mm - 20.3% for the right and 12.8% for the left, the range 51-100 mm - 23.8% for the right and 31.3 % for the left, range 101-150 - 14.8% for the right and 18.2% for the left, range 151-200 mm - 24.1% for the right and 16.8% for the left, in the range over 200 mm - 4,7% for the right and 20.9% for the left, respectively.

The roller-shredder with the right arrangement of knives in the range of 0-50 mm was characterized by higher values of the average value of the percentage of total weight and the total number. This excess was 1.58 times the total weight and 1.2 times the total.

In the grouping interval of 0-50 mm, the probability of crushed particles in the roller with the right arrangement of knives is 27.8%, and with the left - 21.6%. (or 29% more). Exceeding the probability of the interval is 29%.

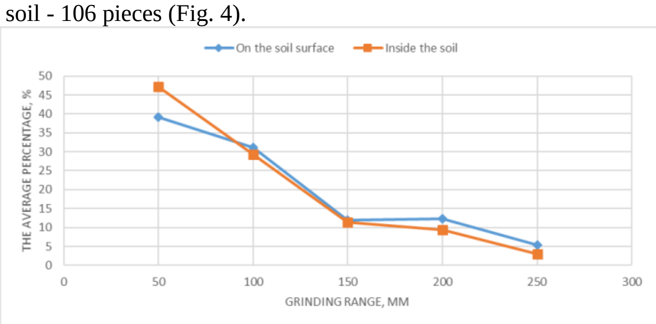
The accumulated probability of the interval 0-100 mm in the roller with the right location of the knives is also characterized by higher values. In the right - 70%, in the left - 62.1%, respectively, and in this interval the accumulated probability of grinding the stems of the roller with the right location of the knives exceeded those of the left by 13%.

The average (weighted by the probability of possible values) value of the random value of the length of the crushed particles of corn stalks for the roller with the right location of the knives was 1 - 65.37 mm for the experiment, 42.814 mm standard deviation and 0.850 coefficient of variation, experiment 2 - 71.06 mm.

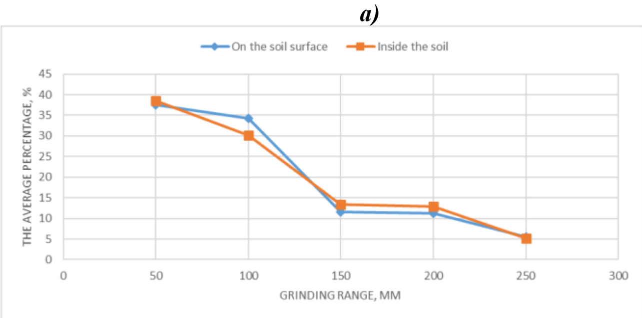
In the roller with the left arrangement of knives, the mathematical expectation was 65.14 mm and 81.33 mm, respectively. That is, the average value of the length of the crushed particles of corn stalks in the roller with the right location of the knives is 5.8% less than the corresponding index of the roller with the left location of the knives.

We note the methodological feature of research to determine the quality of grinding and wrapping plant residues in the soil harrow with a roller (under the right and left placement of knives, as well as mono disk harrow. Collection of crushed residues was carried out both The total amount of crushed residues thus consisted of the sum of residues on the soil surface and those earned on the depth of cultivation with tools.

The average number of crushed parts of the stems in the harrow with the roller was under the conditions of the right placement of knives - 301 pieces, the left - 226 pieces. Under such conditions on the soil surface with the right placement of knives - 115 pieces, in the soil - 186, with the left on the soil surface - 120 pieces, in the soil - 106 pieces (Fig. 4).



a)



b)

Fig. 4. *- Generalized average values of distribution of crushed corn particles for harrow with roller (on the soil surface - 1, inside the soil - 2).*
a - with the right layout of the knives,
b - with the left layout of the knives

In the range less than 50 mm, the percentage of crushed stem particles was:

with the right placement of knives - 39.16%, with the left - 37.48% on the soil surface and 47.18% on the right and 38.5% on the left, respectively, in the soil.

The average number of crushed pieces of corn stalks in the range of less than 50 mm with the right arrangement of knives was 43.17%, and with the left 37.99%. That is, in this range, the harrow with the roller (right location of the knives) by 13.6% exceeded the corresponding values of the tool with the left direction of the knives.

In the range of 51-100 mm, the average percentage of crushed stems for the right direction was -30.19% (31.18% on the soil surface and 29.2% in the soil) and 32.19% (34.28% on the surface and 30,09% in the soil), respectively, for the roller with the left direction of the knives. Analyzing the range of 0-100 mm, we note that the share of crushed stems with the right location of the knives was 36.68%, with the left -35.09%.

That is, the picture of the distribution of crushed stems in the marked range was characterized by a slight excess of the values of the right over the left direction of the knives in the rollers. It is worth noting almost the same pattern of distribution of crushed stem particles in other ranges. Thus, in the range of 101-150 mm, these indicators were as follows: on the soil surface 12.02% in the right and 11.53% in the left, in the soil - 11.36% and right and 11.53% in the left, respectively. In the range of 151-200 mm on the soil surface 12.27% in the right and 11.24% in the left. In the soil 9.31% in the right and 12.95% in the left.

In the range of more than 200 mm on the soil surface 5.37% on the right and 5.47% on the left. In the soil, these figures were 2.95% for the right and 5.16% for the left, respectively.

A significant contribution to the nature and level of damage, shredding of plant residues (sunflower, corn) is made by the working bodies of harvesting machines, engines of technological and transport machines involved in the technological process of harvesting. Thus, the harvester beam resembles the stems with its front part, and the movers, as a result of contact with the stems, break and roll them. Under such conditions, a pattern is formed on the soil surface, which is a combination of different states of stems. First of all, we will highlight the technological tracks, which in most cases do not contain residues of cultivated culture. The second category includes tracks from combines, vehicles, trailers that are involved in the technological process of harvesting and transportation of grain. The third category includes traces of the engines of those vehicles that maneuvered the most convenient route to the combine to load grain and leave the field. These categories of tracks in the field where coarse-stemmed crops were grown, and the analysis of the directions and characteristics of the remaining stem part of the crop, allows us to draw conclusions about the chaotic arrangement of stems. Many of them are broken, partially flattened, sunk into the ground, crushed by engines. The expediency of such an analysis is due to the search for such routes for the movement of rollers on the surface of the field, which would allow the greatest efficiency of grinding and earning crop residues.

However, the chaotic location, lack of dominance and direction of stems, makes it impossible to determine the most rational direction of movement and, accordingly, the type of contact of the working organs of the cat with the stems, which would ensure the most efficient operations of grinding and earning plant parts of stems.

5. Conclusions

Developed and manufactured roller-shredder, the design of which provides for the possibility of direct (left) and inverted to 1800 (right) installation of the cutting edge of the knives relative to their direction of rotation.

A prototype of a combined unit based on a heavy disc harrow BDVP-3.8 was developed and manufactured. The main difference of the above unit is the use of a variable module - roller-shredder, which allows to intensify the process of grinding and wrapping to a depth of 25 cm coarse plant residues. The use of combined units, as well as rollers-shredders in the mono version allows more effective ways to control pests and diseases of corn, reduces uneven grinding and energy costs, intensifies the process of grinding and wrapping.

It was noted that in the range of less than 50 mm the percentage of crushed stems in the roller with the right location of the knives was 20% higher than with the left layout of the knives. The total value of the percentage of crushed stem particles in the range of 0-100 mm for the right was 83.6%, for the left 81.9%. In the range of 101-150 mm the share of crushed stems in the roller with the left arrangement of knives was 11.0%, with the right 7.7%, in the range of 151-200 mm, respectively, 4.6% with the left, and 6.0% with the right, in the range of more than 201 mm, with the left 2.6%, with the right 3.1%.

In the range of 0-50 mm, the average weight of the particles of corn stalks, shredded with a roller with the right location of the knives, exceeded the corresponding grinding rates on the left scheme of installation of knives. This excess of the average weight was, for one sample, the proportion of stems 0.042 g, or 10%.

The average relative to the total weight percentage of crushed stem particles from the total weight of the fraction was for the range 0-50 mm - 20.3% for the right and 12.8% for the left, the range 51-100 mm - 23.8% for the right and 31.3 % for the left, range 101-150 - 14.8% for the right and 18.2% for the left, range 151-200 mm - 24.1% for the right and 16.8% for the left, in the range over 200 mm - 4,7% for the right and 20.9% for the left, respectively.

The average number of crushed corn stalks in the range of less than 50 mm in the combined unit containing a roller with the right arrangement of knives was 13.6% higher than the corresponding indicators of the tool with the left direction of the knives. Under such conditions on the soil surface the percentage of crushed stem particles for the combined unit was with the right placement of knives - 39.16%, with the left - 37.48%, and in the soil these figures were respectively 47.18% in the right and 38.5% in the left.

Analyzing the range of 0-100 mm, we note that the share of crushed stems with the right location of the knives was 36.68%, with the left 35.09%. It is worth noting almost the same pattern of distribution of crushed stem particles in other ranges.

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Theoretical investigation of the removal of halfrums from sugar beet root heads

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Abstract. *Removal of the haulm from the heads of sugar beet to the roots during their harvesting (cutting the main mass) or separation of its residues (when finishing the heads) is a complex technological process associated with either a significant loss of sugar-bearing mass (low cut), or not complete removal of residues (high cut), which significantly degrades the quality of root crops. Therefore, ways to find a complete removal of haulm and its residues from the heads of root crops require research and development of such devices capable of performing this process qualitatively. However, first it is necessary to determine theoretically and experimentally the basic initial conditions under which high quality indicators will be achieved, and losses of sugar-bearing mass during cutting the haulm will be minimal, with the remaining haulm being as small as possible (or they will be absent at all). This paper theoretically and experimentally investigates and determines the loss of sugar mass and remnants of the bud on the heads of sugar beet roots during the separation of the bud and its remnants. It is established that in the interval of working heights of a cut which is equal to 20 ... 60 mm deviation of theoretical calculations from experimental does not exceed on the average 1%.*

KEYWORDS: *SUGAR BEET, ROOT, ROOT HEAD, HICK, MATHEMATICAL MODEL.*

1. Introduction

When performing the technological process of cutting the main mass of haulm and cleaning the heads of sugar beet roots, the basic requirements of the current agro-technological requirements for harvesting sugar beets are not always met. Numerous studies of haulm harvesting have been conducted, but they do not reveal methods for determining the rational height of a no-copy haulm cut from the waste sugar mass and haulm residue on root crops that meet the requirements. This circumstance is an important scientific and technical problem, since reducing the waste of sugar-bearing mass during cutting directly reduces harvest losses, and the high content of haulm in the root crop pile also deteriorates the quality indicators, as well as reduces the sugar yield in their processing.

The most fundamental studies of sugar beet haulm cutting methods were obtained [1, 2]. It was in these works thoroughly determined the height of sugar beet haulm cutting without pinch, at which it would be possible to optimize the waste of sugar-bearing mass going into the cut haulm. In these works, the distribution of heights of sugar beet rootstock appearances is approximated by the normal law, and the shape of the rootstock heads can be given by different shapes. Наприклад, конусом, зрізаним конусом або сферою. For example, a cone, a truncated cone or a sphere. However, these studies are quite approximate and difficult to use to model the process of copyless cutting.

Therefore, in order to reduce the loss of sugar mass and, accordingly, increase the productivity of machines for the separation of the tops, it is necessary to develop basic provisions for determining the rational height of the copyless cut. It is necessary, first of all, to develop a mathematical model of the technological process of copyless cutting of the bud at the root of sugar beet roots. This will give grounds to further theoretically determine the dependences of sugar loss and remnants of the bud on the heads of root crops on the height of the copyless cut for different agrophysical characteristics of crops and varieties of sugar beet roots. Next, it is necessary to carry out experimental testing of this mathematical model of the specified technological process and to determine the limits of its practical application to optimize the parameters of working tools used to cut the haulm from the heads of root crops.

2. Materials and Methods

Preliminary studies carried out by A.A. Vasilenko, P.F. Volk, M.M. Zuev, L.V. Pogorely, M.V. Tatianka proved that there are linear relationships between the height of sugar beet root head appearance above the soil surface and the size parameters of its body. It was also proved that the main part of sugar beet root heads has the shape of a cut cone. The maximum diameter, which is more than 80% of the roots, is below the level of the soil surface.

It is also found that at the very head of the rootstock the haulm is so densely arranged that it can be modeled as a homogeneous cylindrical body. Therefore, with a known distance from the top to the base of the green leaves, it is possible to determine the diameter of the haulm cylinder. According to the known law of distribution of the height of appearance of the heads of root crops above the soil surface and the functional dependences of the head and haulm parameters on the height of appearance of the root crops head, we can describe the patterns of distribution of their masses relative to the soil surface..

This allows the construction of a mathematical model of the technological process of copierless cutting of the haulm with subsequent justification of the optimal cutting height. However, the main thing, first of all, is to build first the geometric model of sugar beet root ball head, which will simulate the most common type of sugar beet root ball before their harvesting.

Constructed model of sugar beet root ball head, which is above the soil surface level, is shown in Fig. 1.

This model shows the head of sugar beet root in the form of a cut cone, the base of which is located on a horizontal straight line (conditional level of the soil surface), and the height is designated as *h*. Also characteristic points and linear and angular dimensions are given, the nature of which is clear Fig. 1.

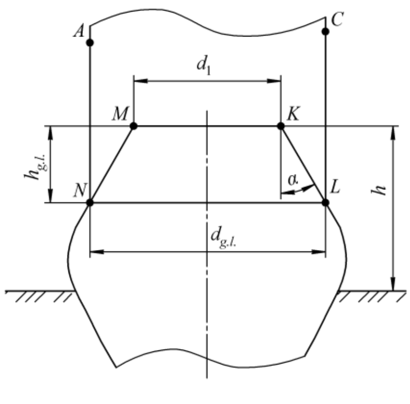

Figure 1. *Geometric model of sugar beet root head*

Based on this geometric model, we can formulate analytical relationships for the parameters of the sugar beet root and haulm, having the following form:

$$\left.\begin{aligned} h_{gl} &= a \cdot h + b; \\ d_1 &= m \cdot h + n; \\ d_{gl} &= d_1 + 2 \cdot h_{gl} \cdot \tan\alpha \end{aligned}\right\}, \qquad (1)$$

where h_{gl} – the distance from the top of the head to the base of the green leaves; h – the height of the head above the level of the soil surface; d_1 – the diameter of the top of the root head; d_{gl} – haulm diameter; α – half the angle of the taper of the head; a, b, m, n – constants.

Analyzing the location of root crops relative to the soil surface, six groups of characteristic location of the bud and root heads were identified (Fig. 2).

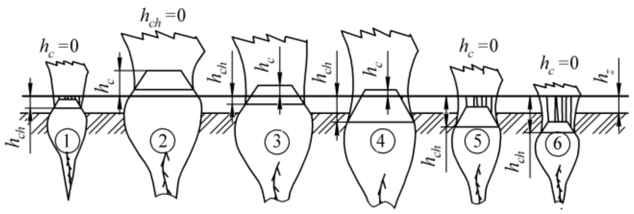

Figure 2. *Characteristic 6 cases of root and haulm location above the soil surface: h_c, h_{ch} – respectively the height of the tops and the head of the root crop*

We obtained analytical relationships to determine the location of the root and haulm relative to the soil surface, the passage of the cutting plane relative to the top of the head and the base of the green leaves, the height of the head and haulm cut, the amount of sugar loss and residual haulm. But the cutting height of the heads h_z of root crops and the cutting height of the haulm h_{ch} according to different cutting planes (and there can also be 6 such planes, according to these cases) can be described by the following dependencies:

– location of the root crop $h_i > 0$, $h_i \geq h_{gl}$; passing the plane of the cut $h_z \geq h_i$:

$$h_c = 0;\ h_{ch} = h_{gl} - h_c - h_z; \qquad (2)$$

– location of the root crop $h_i > 0$, $h_i \geq h_{gl}$; passing the plane of the cut $h_i > h_z \geq \left(h_i - h_{gl}\right)$:

$$h_c = h_i - h_z;\ h_{ch} = h_{gl} - h_i - h_z; \qquad (3)$$

– location of the root crop $h_i > 0$, $h_i \geq h_{gl}$; passing the plane of the cut $h_i > h_z < \left(h_i - h_{gl}\right)$:

$$h_c = h_i - h_z;\ h_{ch} = 0; \qquad (4)$$

– location of the root crop $h_i \leq h_{gl}$; passing the plane of the cut $h_z \geq h_i$:

$$h_c = 0;\ h_{ch} = h_{gl} - h_c - h_z; \qquad (5)$$

– location of the root crop $h_i \leq h_{gl}$; passing the plane of the cut $h_z < h_i$:

$$h_c = h_i - h_z;\ h_{ch} = h_{gl} - h_i - h_z; \qquad (6)$$

– location of the root crop $h_i \leq 0$;

– passing the plane of the cut $h_i \leq 0$:

$$h_c = 0;\ h_{ch} = h_{gl} - h_c - h_z; \qquad (7)$$

Accordingly, for each of these cases, we analytically obtained calculated expressions for calculating the volumes: cut root V_r and cut haulm V_q. They look as follows:

– case 1:

$$V_r = 0;\ V_g = \frac{\pi \cdot h_{ch} \cdot d_{gl}^2}{4} - \frac{\pi \cdot h_{ch} \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12}, \qquad (8)$$

– case 2:

$$V_r = \frac{\pi \cdot h_c \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12};$$

$$V_g = \frac{\pi \cdot h_{ch} \cdot d_{gl}^2}{4} - \frac{\pi \cdot \left(h_{ch} - h_c\right) \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12}, \qquad (9)$$

– case 3:

$$V_g = 0;\ V_r = \frac{\pi \cdot h_c \cdot \left(d_{dl}^2 + d_{gl} d_c + d_c^2\right)}{12}, \qquad (10)$$

– case 4:

$$V_r = 0;\ V_g = \frac{\pi \cdot h_{ch} \cdot d_{gl}^2}{4} - \frac{\pi \cdot h_{gl} \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12}, \qquad (11)$$

– case 5:

$$V_r = \frac{\pi \cdot h_c \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12};$$

$$V_g = \frac{\pi \cdot h_{ch} \cdot d_{gl}^2}{4} - \frac{\pi \cdot \left(h_{ch} - h_c\right) \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12}, \qquad (12)$$

– case 6:

$$V_r = 0;\ V_g = \frac{\pi \cdot h_{ch} \cdot d_{gl}^2}{4} - \frac{\pi \cdot h_{ch} \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12}. \qquad (13)$$

Losses of sugar-bearing mass and haulm residues for root crops of a given height interval of performances above the ground surface are determined by the formula:

$$M_i = F\left(h_i; h_c\right) \cdot P\left(h_i; h_{i+1}\right) \cdot N_{i,}, \qquad (14)$$

where $F(h_i, h_c)$ – loss of sugary mass or haulm residue, for root crops; $F(h_i, h_c) = V_r \cdot \rho$, for the tots $F_c(h_i, h_{ch}) = V_q \cdot \rho_g$, where V_r, ρ and V_q, ρ_q – volume and density of sugar beet root and haulm, respectively; N_i – the number of root crops of a given interval per crop unit area; $P(h_i, h_{i+1})$ – the probability of occurrence of a given interval of heights of protruding heads of root crops above the soil surface, determined according to this expression:

$$P\left(h_i; h_{i+1}\right) = \frac{1}{\sigma\sqrt{2\pi}} \int_{h_i}^{h_i+1} \exp\left(-\frac{\left(h - m\right)^2}{2\sigma^2}\right) dh. \qquad (15)$$

In this expression, the integral cannot be defined in quadrature, so we determine the probability of occurrence of beet roots of a given height interval by numerical integration using the Simpson formula. Summing the haulm residues and losses of sugar mass for all height intervals of performances, we obtain the total haulm residues *BM* and losses of sugar mass *GM* per unit area using these analytical expressions:

$$BM = \sum_{i=a}^{b} \left[N \cdot F\left(\frac{h_i + h_{i+1}}{2}; h_c\right) \cdot \left(\frac{h_{i+1} - h_i}{3m} \sum_{j=0}^{m} c_j \cdot f(h)\right) \right], \qquad (16)$$

$$GM = \sum_{i=a}^{b} \left[N \cdot F_c\left(\frac{h_i + h_{i+1}}{2}; h_c\right) \cdot \left(\frac{h_{i+1} - h_i}{3m} \sum_{j=0}^{m} c_j \cdot f(h)\right) \right], \qquad (17)$$

where m – number of intervals: $m = 2U$; $U = 1, 2, 3, 4, ...$; c_j – coefficient for the values of the subintegral function at the corresponding points, c_j = 1, 2, 3, 4, 2, 4,…,2, 4, 1.

3. Results and discussions

Verification of the correctness of the theoretical studies can be carried out using the results of the experimental study of the process of rootless cutting, published in [1]. In the conducted experimental studies, the distribution of heights of protruding heads of root crops relative to the soil surface, waste of sugar mass and haulm residue on the root crop when setting the knife of the cutting unit relative to the soil surface at a height of 10 - 50 mm with an interval of 10 mm was determined. Root crop yield was also determined. According to the data of experiments, it is possible to carry out mathematical modeling of a copierless cut on PC with the help of a composite program. Using the distribution of the heights of the protruding heads of root crops, we determined the mathematical expectation m standard deviation σ. By determining the dependences of the head apex diameter and the height of the green leaf zone on the height of the performance, as well as the head taper angle, we obtained the simulation results and compared them with the experimental data. A comparison of theoretical and experimental studies of the no-taper cutting process is shown in Fig. 3.

Comparing the results of experimental and theoretical studies, we can conclude that the theoretical model generally reflects the trends in the dependence of sugarcane waste and haulm residues on the height of the no-tillage cut obtained experimentally.

To verify this mathematical model, experimental investigations were carried out. The initial characteristics of sugar beet roots and the beet field on which the research was conducted were determined: crop capacity 0.5 t·ha^{-1}, mathematical expectation m = 55.4 mm, standard deviation σ = 16.9 mm, the average value of the taper angle of the root head 78 deg, the diameter of the top of the head $d_1 = 0.58h + 14.2$, height of the zone of green leaves $h_{gl} = 1.02h + 11$.

The results of the comparison of theoretical and experimental studies are shown in Fig. 3.

Determination of quality indicators was carried out by the methodology of the Institute of bioenergy crops and sugar beet NAAS, quite accurate, but characterized by a large amount of labor intensity than it is limited by the number of experiments required. We determined the differences between the theoretical and experimental data (Table 1).

Theoretical calculations compared to experimental studies deviate as follows:

– sugar waste according to the research of other scientists from -1.4% to + 4.7%, according to our research – from -0.3% to + 1.8%;

– haulm residues according to studies by other scientists from -1.2% to 3.6%, according to our own studies from -0.3% to 0.7%.

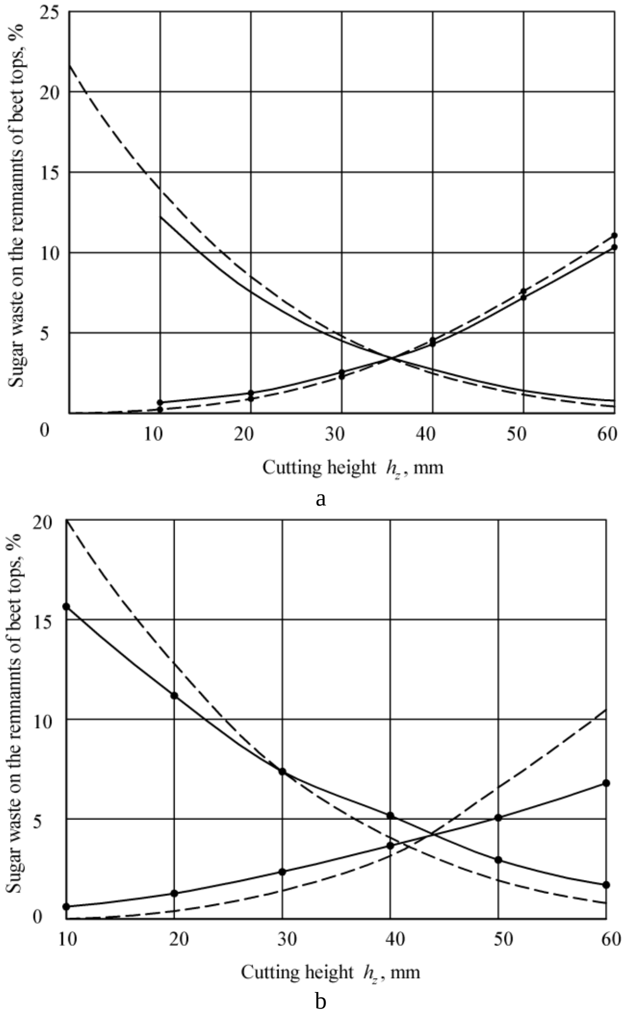

Figure 3. *Dependence of losses of sugar-bearing mass (a) and haulm residues (b) on the height h_z of the haulm cut from the heads of sugar beet roots*

Tabel 1. *Deviation of the results of theoretical and experimental research*

h_z, mm	10	20	30	40	50	60	10	20	30	40	50	60
							According to other researchers					
Weight loss, %	1.8	0.9	0.3	-0.2	-0.2	-0.3	4.7	1.1	0.2	-1.4	-0.6	-0.9
Leaves of the tops, %	-0.3	-0.2	-0.2	0.3	0.4	0.7	-0,6	-1.2	-1.0	-0.2	1.4	3.6

We found that one of the reasons for the deviation of the results of theoretical and experimental studies is not considered in the mathematical model of the additional cleaning of the haulm and damage to the roots, which occur in the technological process of digging sugar beet bodies from the root harvesting machines.

With sugarcane residues from 1% to 5%, close to the agrotechnical requirements, the deviation of the results of theoretical studies from the experimental ones does not exceed 0.7% for haulm residues and 0.5% for sugarcane residues. Therefore, this mathematical model can be used to predict sugarcane residues and haulm residues of different sugar beet varieties.

By constructing on the basis of the characteristics of the dependencies of the obtained analytical relationships, we can determine the height of the peakless cut with the predicted waste sugar mass and haulm residues.

4. Conclusion

A mathematical model of the process of separating the main mass of the haulm leaves by means of a birchless cut and an algorithm have been developed, which makes it possible to determine the optimal height of installation of the birchcutter above the ground level in accordance with the minimum allowable losses of sugar-bearing mass and the agrophysical characteristics of crops and root crops. As a result of the research it was found that for existing agrophones (σ = 10...30 mm, m = 40...60 mm) the cutting plane should pass not higher than 60 mm above ground level.

The dependence of losses of sugar-bearing mass and haulm residues on the height of the pickerless cut was determined experimentally. When comparing with theoretical calculations, it was found that in the interval of cutting height 20-60 mm above the soil level, the deviation of the results of theoretical studies from the experimental data does not exceed 0.7% for haulm residues and 0.9% for losses of sugar mass. Therefore, the proposed mathematical model can be used to justify the cutting height.

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ПОВЫШЕНИЕ НАДЕЖНОСТИ СЕЛЬСКОХОЗЯЙСТВЕННЫХ РОБОТОВ ПРИМЕНЕНИЕМ КОНСТРУКЦИОННЫХ ПЛАСТИКОВ

INCREASING THE RELIABILITY OF AGRICULTURAL ROBOTS APPLICATION DESIGN PLASTICS

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Abstract: *It is shown that to increase the reliability of agricultural robots, it is necessary to use polymeric composite materials. Parts made of polymeric composite materials do not require maintenance.*

KEYWORDS*: AGRICULTURAL ROBOTS, RELIABILITY, COMPOSITE MATERIALS, CARBON FIBER.*

1. *Вступление*

В ближайшем обозримом будущем развитие технического обеспечения агросектора Украины будет связано с введением эксплуатацию беспилотных агрегатов, их дистанционным управлением и контролем производственных процессов. Крупнейшие производители с.-х. техники предлагают достаточно развитые телематические системы (JD Link, Telematics и др.) и целый спектр софтов для систем точного земледелия (AMS, Trimble, AFS, SMS, PLM, Cropwise и др.). Уже сегодня можно безопасно эксплуатировать беспилотную технику, отдельные модели которой представили тот же John Deere, CNH, CLAAS и другие производители. Обычно, эти беспилотные агрегаты сделаны на базе конструкций, базой которых был традиционный трактор тягово-энергетической концепции.

Однако, появилась еще одна категория техники, которая с самого начала проектирования создавалась как крупные сельскохозяйственные роботы. К таким можно отнести автономную платформу Raven Autonomous Platform (рис. 1) – первый серийный агроробот, который продается [1].

Рис. 1 - Автономная платформа Raven Autonomous Platform на посеве

Платформа может использоваться на трех технологических операциях: посев, разбрасывание минеральных удобрений и опрыскивание. Для этого она агрегатируется с соответствующими исполнительными механизмами. Сама же платформа построена на рамной основе, на которой установлен дизель, а движители колесного типа приводятся в движение с помощью гидростатики. При выполнении посева, платформа движется перпендикулярно продольной оси, а при разбрасывании удобрений и внесении средств защиты растений – вдоль нее.

В прошлом году в фермерских хозяйствах мира эксплуатировалось 10 таких платформ. Усовершенствование конструкции происходит при сотрудничестве производителя Raven и специалистов Olds College (Канада). Учитывая большую загрязненность полей Украины минами и остатками снарядов, применение именно беспилотных роботов является актуальным.

2. *Постановка проблемы*

Анализируя конструкции навесного оборудования нами установлено, что сеялка выполнена в рамках традиционного конструирования без применения кардинально новых технологий (рис.2.). Очевидно, производитель решает задачу повышения технического уровня самой платформы, а не оборудования. Однако такой подход не способствует повышению надежности и, соответственно, автономности платформы. Периодичность обслуживания исполнительных рабочих органов осталась на прежнем уровне, как и в классических машинах.

Рис. 2 - Посевная секция платформы Raven Autonomous Platform выполнена традиционными методами машиностроения.

По нашему мнению, в конструкции

3. *Решение рассматриваемой задачи*

Нами предложено применить в трибосопряжениях посевных секций самосмазывающиеся полимерно-композиционные материалы (ПКМ). Имея положительный опыт внедрения ПКМ в с.-х. технику [2 – 4] и обосновав научные основы работоспособности их в данном механизме, можно решить следующие задачи для Raven Autonomous Platform:

- полностью ликвидировать техническое обслуживание посевных секций, оставив только технологические настройки;
- повысить точность глубины посева (сейчас наименьшее деление шкалы глубины составляет ½ inc, а это большая погрешность для условий Украины) до 0,5 см;

- повысить долговечность агрегата за счет эффекта переноса в трибосопряжениях, который активно проявляется за использование предложенных нами ПКМ.

Наличие углеродных волокон и термически расширенного или коллоидного графита в структуре разработанных ПКМ обеспечивают эксплуатацию трибосопряжений в режиме трения без смазки, снижают негативное влияние абразива на эффективность их работы. Вероятность заклинивания полимерно-композитных пар трения, имеющая место при трении системы «металл-металл», минимальна.

Запатентованные технические решения [5, 6] сегодня эффективно применяются в Украине. Это действующие патенты.

Композит в соответствии с требованиями условий эксплуатации получали на двухкомпонентном опытном экструдере (рис. 3). Данный экструдер позволяет получить композиты на основе термопластичных связующих с введением в полимерную матрицу колоидного и термически расщепленного графитов, измельченных углеродных волокон, других компонентов.

Производительность агрегата составляет от 9 до 40 кг/час в зависимости от состава композита и природы полимерной матрицы.

Рис. 3 - Двухкомпонентный опытный экструдер для получения полимерно-композиционных материалов.

Полученный композит перерабатывали в детали (рис. 4) методом литья под давлением известными методами и оборудованием.

Рис. 4 – Деталь трибосопряжения посевной секции.

Владея рассчетными данными об силовой картине в подвижных сочленениях посевных секций [7], используя опытный экструдер, можно изготавливать детали из композитов, максимально соответствующих условиям работы по нескольким критериям (табл. 1).

В табл 1. приведены только два критерия выбора. На самом деле их может быть больше, в зависимости от конкретных условий эксплуатации и требований к повышению надежности и безопасности.

Таблица 1 – Некоторые критерии соответствия условий работы и свойств детали

Параметр	Показатель	
	Необходимое	Свойства детали
Усилия, действующие на деталь, Н	2300…3000	9800
Коэффициент трения	0,25…0,4	0,2…0,3

4. *Заключение*

Таким образом, на основе накопленного научно-практического опыта можно сделать вывод, что применение самосмазующих полимерных композитов конструкциогного назначения в трибосопряжениях агророботов обеспечит повышение их надежности и качества выполнения агротребований и мы рекомендуем внедрять их в конструкцию исполнительных механизмов.

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VIBROACOUSTIC ANALYSIS OF THE CAB OF AN AGRICULTURAL TRACTOR

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1. Introduction

The aim of the study was to assess the external and internal noise of an agricultural tractor. On the basis of the measurements and analyses carried out, the existing state of noise in the cab was demonstrated and a ranking of noise emission sites was developed, and solutions were selected to give the potential to reduce noise at the driver's ear to 80 dB.

2. Research methodology

URSUS 11054

Engine type	Diesel, turbocharged with intercooler
Power at 2,200 rpm [kW]	81
Capacity [cm³]	4400
Tractor dimensions [m]	4.3 x 2.4x2.7
Weight without weights [kg]	4450

Stages of research implementation

Acoustic measurements

Stage I. Vibroacoustic measurements of the cab of URSUS 11054 agricultural tractor

- Determining the conditions for setting up the tractor to achieve the desired operating conditions (2.200 engine revolutions and a speed of about 7.5 km/h).
- Noise measurement inside the cab at a point near the driver's ear to determine the required noise reduction along with the recommended reduction spectrum.
- Measurement of exterior noise at a point 7.5 m from the centerline of the runway .

Stage II. Acoustic analysis for noise reduction strategies

- Examination of the normal component of the sound intensity from all surfaces inside the cab using a two-microphone probe.
- Analysis of the noise sources on the tractor.
- Acoustic analysis of the acoustic energy emissions from the tested partitions to determine the required noise reduction from each partition.
- Development of noise reduction strategies

Stage III. Acoustic concept and vibroacoustic guidelines for the cab of an agricultural tractor

- Noise measurements inside the cab using prototype solutions to determine their effectiveness.
- Verification of the adopted noise reduction strategy.t of a noise reduction strategy.

Cabin interior sound level

- Measurement of noise level in the cabin interior was conducted in order to determine the noise level in the cabin and to assess the required noise reduction to 80.0 dB(A).
- The measurement was made with a class I sound level meter type SVAN-971, serial number 34929. The measurement was made at the ear of the tractor driver (point in compliance with Directive 2009/76/EC).
- The driver was not wearing any particularly thick clothing, scarf or headgear. There was no object on the tractor that could distort the noise level.
- Additional devices such as windscreen wipers or the heating system blower were switched off.
- Components operating simultaneously with the engine (engine fan) were switched on.
- Measurements were made while driving on a non-sloping paved surface.
- The weather during the measurements was windless and dry. The time taken to drive the tractor at the test speed was at least 10 seconds. Three tractor passes were made, and the maximum value obtained was given as the result. All opening elements (windows and doors) were closed. The tractor was driven at a speed of approximately 8 km/h at 2,200 engine rpm.

Sound level outside the cabin

- The measurement was carried out with a class I sound level meter type SVAN-958 serial number 20877.
- The measurement was carried out at 7.5 m from the centreline of the crossing at a height of 1.2 m.
- There was no object on the tractor that could distort the noise level.
- Additional devices such as windscreen wipers or the heating system blower were switched off.
- Components operating simultaneously with the engine (engine fan) were switched on.
- Measurements were made while driving on a non-sloping paved surface.
- The tractor was driven at a speed of approximately 8 km/h at 2,200 engine revolutions per minute.
- During the measurements, the weather was windless and dry.
- The time taken to drive the tractor at the test speed was at least 10 seconds.
- Three tractor passes were made, and the maximum value obtained was given as the result.
- The difference between the results of two consecutive passes did not exceed 2 dB. All openings (windows and doors) were closed.
- The maximum level recorded is the result of the measurement (LA,max with SLOW time constant).
- The permissible sound level outside the cab for the tested tractor according to Directive 2009/63/EC is 89 dB(A).

3. Results

The red dotted line marks the 80 dB level, the attainment of which is the goal of the project. For the purpose of achieving the goal, the required reduction in the value of the maximum sound level at the driver's seat by 5 dB should be assumed. The dominant frequency bands in the noise spectrum are 500 Hz and 1000 Hz.

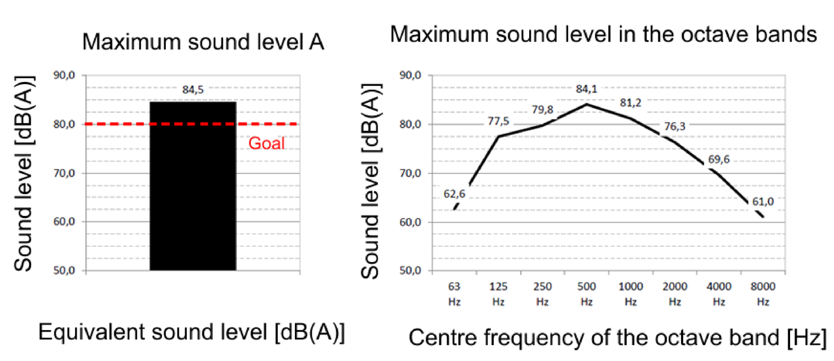


Fig. 1. Cabin interior sound level

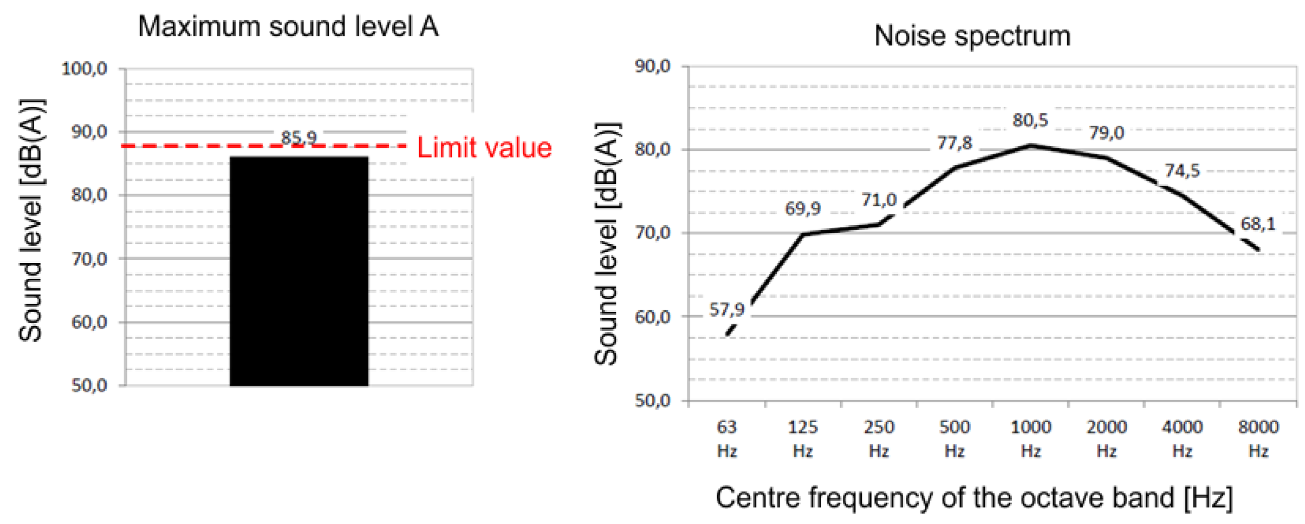
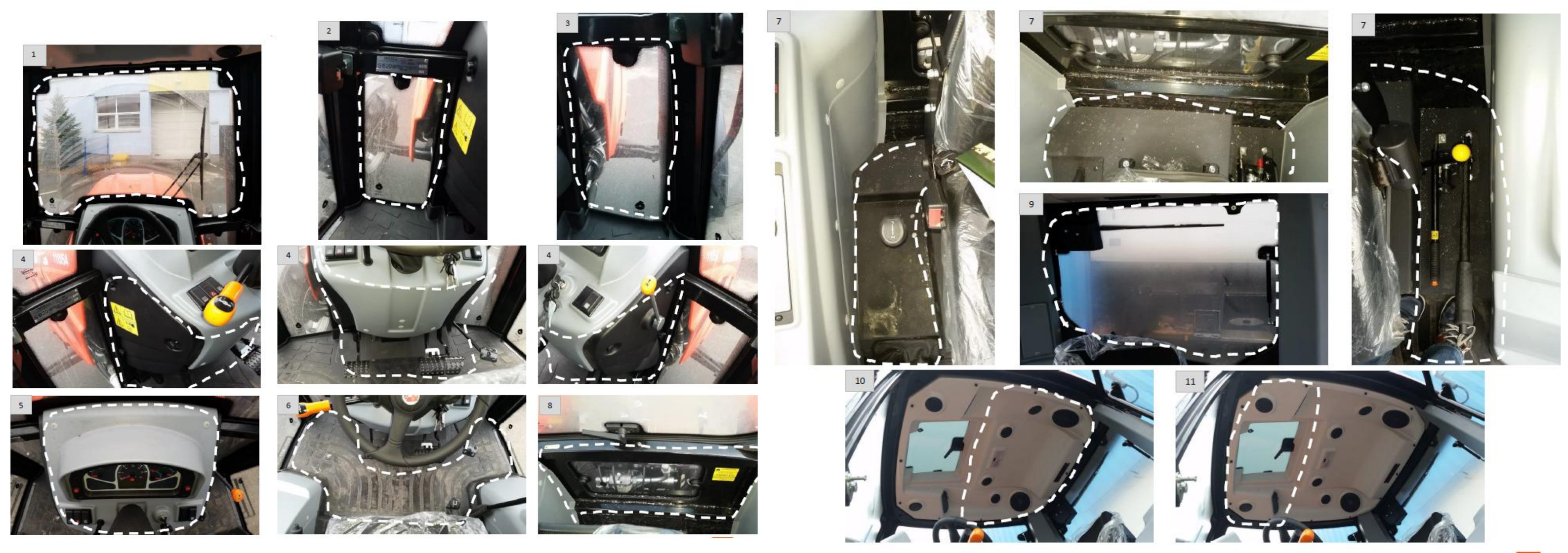


Fig. 2. Sound level outside the cabin

Noise emission in the cabin interior



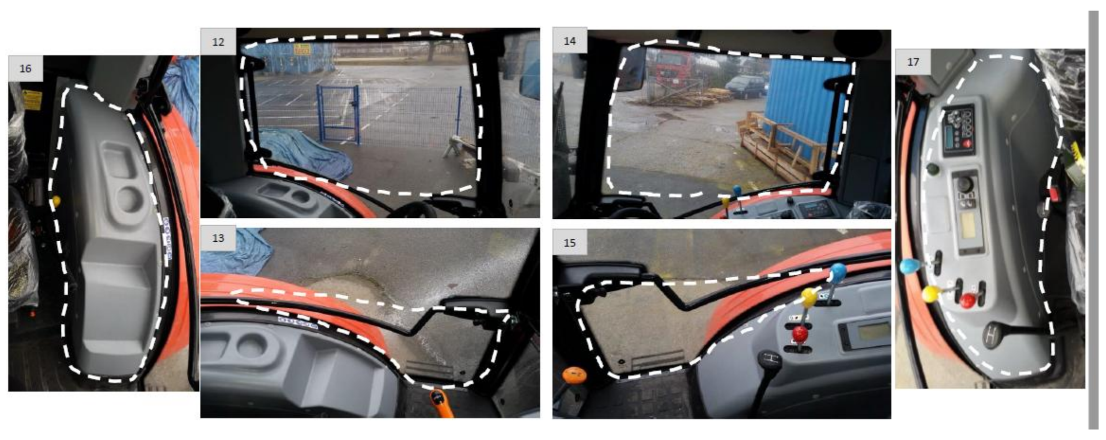
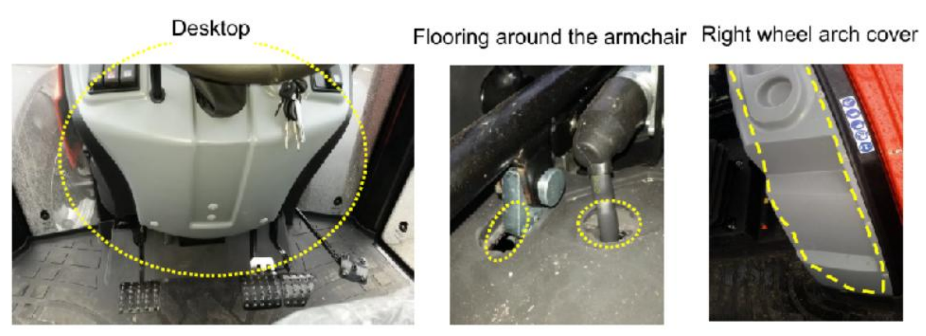


Fig. 3. Numbering of measurement segments

4. Conclusion

On the basis of the performed measurements it can be stated that the places with the highest level of noise emission inside the cabin are: desktop (areas 4-5) and including desktop shields and the space between the shields and the floor - 37% of acoustic energy part of the floor in the vicinity of the driver's seat marked with number 7 - 24% of acoustic energy right wheel arch shield - 10% of acoustic Energy.



The following solutions should be implemented to reduce noise to below 80 dB inside the cabin:

Reduction of noise emissions

- Reduction of desktop noise by:
  - Adaptation of the engine cover
  - Adaptation of the engine bulkhead
  - Adaptation of the console
- Reduction of noise emitted from the floor in the vicinity of the seat by sealing holes in the floor or introducing additional damping
  - Inspection to check sealing possibilities
- Reduction of noise emitted from the wheel arch cover by:
  - Adaptation of wheel arch protection
- Increasing the acoustic absorption of the interior
  - Use of an acoustic headliner

Основни принципи при проектиране на почвообработващите операции

Ivan Mortev
ISSAPP "Nikola Poushkarov"

Резюме: *Представени са необходимостта, основните видове и изискванията към почвообработващите операции. Дадени са зависимости за определяне на подходяща почвообработваща машина и трактор за проектиране на икономичсеки ефективни агрегати за почвообработка. Разработено е имитационно моделиране на параметрите на почвообработката.*
КЛЮЧОВИ ДУМИ: *ПОЧВООБРАБОТКА, ПАРАМЕТРИ НА ПОЧВООБРАБОТКА, ПРОЕКТИРАНЕ НА АГРЕГАТИ ЗА ПОЧВООБРАБОТКА.*

Abstract: *The necessity, the main types and the requirements to the soil tillage operations are presented. Dependencies are given for determining a suitable tillage machine and tractor for designing economically efficient tillage units. Simulation modeling of tillage parameters has been developed.*
KEY WORDS: *TILLAGE, TILLAGE PARAMETERS, DESIGN OF TILLAGE UNITS.*

Значение на обработката на почвата

С обработката на почвата се подобряват на физичните, водните и въздушните свойства на повърхностния почвен слой, така се създават благоприятни условия за растежа и развитието на разстенията и се съдейства за повишаване на устойчивостта им към вредителите (Национална програма за контрол на вредителите по трайните насаждения през зимния период, София 2013). Чрез основната обработката на почвата се заравят растителните остатъци и плевелите и така се активизира процеса на минерализация на растителните остатци и се ограничава инфекционния фон от причинители на болести. Чрез подходяща обработка се постига предпазване на почвата от водна и ветрова ерозия, запазва се почвената влага тъй като се разрушават почвените капиляри и се намаляват изпаренията от тях. При есенната дълбока оран с обръщане на пласта и продълбочаване на подорния слой се извършва едновременно обръщане, разрохкване и частитчно размесване на орния слой, заорава се горния разпрашен пласт и на повърхността се изважда оструктурен долен хоризонт, унищожават се плевелите и другите разстителни остатъци, заоравят се дълбоко плевелните семена ако се внасят торове те също се заравят на по-голяма дълбочина за да се използват интензивно. Основната почвена обработка се извършва след приключване на всички други агротехнически мероприятия.

Видове почвообработки

Обработките те се делят на два основни вида основни и повърхностни.

Основните обработки на почвата са най-трудоемките енергонатоварени операции. Към тях се отнасят дълбоката оран и дълбокото продълбочаване.

Повърхностни обработки са култивиране, дисковане, брануване, фрезоване чрез тях се постига: разрохкване, размесване и наситняване на почвата на по малка дълбочина до 15 см; подрязване и унищожаване на плевелната растителност; инкорпориране на растителни остатъци, торове и пестициди; осигуряване на оптимални условия (равна повърхност, структура на почвата и дълбочина) за извършване на сеитба или разсаждане на междините култури а също така за прокарване на поливни бразди.

Комбинирани обработки се прилагат когато се извършва едновременно две повърхностни, две основни или основна и повърхностна обработка.

Изисквания към почвообработките

- Да бъде съобразена с технологиите за отглеждане на съответната земеделска култура. Всяка технология за поддържане на почвената повърхност има за цел да осигури всички условия за растеж и развитие на земеделските култури, както и да улесни практиките по отглеждането им.
- Да изпълнява агротехническите изисквания на съответната земеделска култура.
- Работните органи трябва добре да подрязват плевелите 98-99%.
- Плевелите да не се задържат по режещите ръбове на работните органи и по стойката.
- Почената повърхност да бъде равна да няма високи гребени и дълбоки бразди.
- Почвата да бъде добре да разрохкана, размесена и разтрошена.
- При повърхностните обработки да не се изнася на повърхността влажната почва, тъй като това води до изсушаването и.
- Да се поддържа постстоянна дълбочина на обработка по време на работа.
- Когато се работи в междуредия да не нарушава целостта на всички части от разстенията, корени, стъбла, клони и др. Да са съобразени с конкретните изисквания на земеделската култура. Когато се работи върху освободени площи да се съобразязва с кореноообитаемиат почвен слой от културата която предстои да се засява.

Изисквания на които трябва да отговарят машините за обработка на почвата

За механизираното осъществяване на обработката на почвата се използват селскостопански машини, които трябва да отговарят на определени изисквания:

1. Да отговаря на свойствата на надежността: безотказност, траиност, ремонтопригодност и съхраняемост;
2. Да са икономически ефективни;
3. Да имат възможност за регулиране на дълбочината на обработка и работната ширина;
4. Да отговарят на съвременните тенденции в производството на подибни машини.
5. Да извършват определената работа в съответствие с агротехническите изисквания.

Определяне на параметрите на машина за обработка на почвата

Определяне на оптималният размер на машината

Оптимизирането на размера на машината е една от техниките за намаляване на производствените разходи. Когато машината е твърде малка, оперативните разходи могат да бъдат по-високи и намалената й мощност ще изисква по-голям брой часове за завършване на операцията. Възможно е също така да не се използва оптимално трактора, когато размерът на машината е малък за наличната теглителна сила. Когато машината е твърде голяма, теглителната сила е ограничителният фактор и машината може не дава желаните резултати или животът на трактора може да бъде съкратен, защото модерните трактори са проектирани да работят при по-малки натоварвания и по-бързи скорости.

Оптималният размер на машината може да бъде избран от две различни гледни точки:
Първата се основава на времето, необходимо за завършване на операцията, втората се основава на количеството мощност, налична от трактора. Използваният процес зависи от ситуацията. Когато ограничителният фактор е време, препоръчително е, първо да се определи наличното време (навременност) за завършване на операцията и след това определяне на размера на необходимата машина. След като се

определи размерът на машината, се изисква размерът на трактора да бъде съгласуван с така определената машина. Големият приоритет за своевременността може да доведе до изчисление, което ще изисква по-голям трактор за агрегатиране на машината. Когато ограничителният фактор е теглителната сила, препоръчва се да се определи максималния размер на машината, която може да се агрегатира към трактора. Когато вече е наличен трактор. Ако имаме да определим необходимия агрегат за основна обработка при агротехнически срок за извършване една седмица на площ от 500 декара първо определяме каква е необходимата часова производителност. При пет дневна седмица 100 декара на ден, тук трябва да се има предвид дали ще се работи на една смяна или две смени. При две работни смени, може производителността на агрегата да бъде 50 декара на работна смяна, при 10 часа работна смяна 10 декара часова производителност е необходимо да има избраната машина. Тук е добре да се имат предвид и почвеното съпротивление и дълбочината на обработка на база на което се изчислява необходимата теглителна сила. На база на всички тези изисквания се избира агрегат за стопанството и от там трактор и работна машина. От съществено значение са също и природните условия в които машината ще работи, не само почвата с нейното теглително съпротивление но и наклоните на терена, климата оказва влияние на работата, спецификата на производството

Рационалното използване на машината може да се определи на база на разходите за извършване на механизираните операции за конкретна ситуация. Добре е да бъдат взети под внимание възможно повече показатели за да се доближават до реалните ситуации. Колкото повече променливи се въвеждат по време на изчисляване на разходите по-малка ще бъде вероятността за непредвидени изненади.

Ефективно използване може да се получи само по оценка на дадена марка машина, възниква въпроса и за цената, което също окозва влияние на себестойността. Голяма машина може да не се използва достатъчно или малка която не може да осигури извършване на работата в агротехническия срок. Голямата машина която извършва операциите много бързо може да се използва за извършване на услуги, но от друга страна голямата машина не е рентабилна за малки полета където тя трудно маневрира.

Сменната норма за работа се определя по формула 1:

$$Нсм = Вр.Vр.Тр.Ко, \qquad (1)$$

където *Нсм* е сменната норма за изработка, декари; *Вр* - работната ширина на агрегата, метри; *Vр* - средната работна скорост на агрегата, км/ч; *Тр* - чистото работно време в смяната /около 6 до 7/, часове; *Ко* - обобщеният коригиращ коефициент, отчитащ редица фактори, като дължина на лехата, наклон на полето, каменистост, препятствия и др.

Тази производителност се различава от действителната. Ако се приеме, че операторът работил средно 7 часа от 10 часов работен ден, ефективността на времето за дълбоката оран E_f е равна на 70%, коефициента на работната скорост е 80%, коефициента на използване на работната ширина на машината $K_B=95\%$ (Harry L. Field and John B. Solie, Introduction to Agricultural Engineering Technology, A Problem Solving Approach, Third Edition, Oklahoma State University, Stillwater, OK, USA) Тогава ефективната полска производителност се различава от теоретичната и ще бъде:

$Нсм = V_E \times B_E \times E_f = V\times K_V\times B\times K_B\times E_f = 5\times0,8\times1\times0,95\times0,7=2.66$ декара за час

От тук се вижда, че теоретичната производителност 5 декара за час се различава от действителната ефекивна производителност която е 2.66 декара за час.

Часовият разход на гориво по принцип се определя въз основа на предварителна информация за стойностите на коефициента на използване на номиналната мощност на двигателя на трактора за конкретния агрегат. При извършване на почвообработки коефициента на използване зависи от специфичното съпротивление на почвения тип. За условията на нашата страна и почвените типове, максималната стойност на почвеното съпротивление се приема f_{max}= 10 N/cm^2. На тази база коефициента на използване на мощността за конкретния агрегат при дадените регионални условия се определя по израза:

$$\eta = \frac{f}{f_{\max}},$$

където f, N/cm^2 е почвеното съпротивление за конкретния почвен тип.

Часовият разход на гориво се определя по израза:

$$R_г = N_n q \eta, \ kg/h,$$

където N_n е номиналната мощност на двигателя на трактора, *hp*

q - специфичен разход на гориво в *kg/hp.h.*

Специфичния разход на гориво (Устройство на АТК) варира в границите 200-270 g/kWh за дизеловите двигатели каквито са най-често при тракторите и другите самоходни машини в земеделието. Някои съвременни марки постигат нисък специфичен разход на гориво от 200 g/kWh.

Правилното агрегатиране на машината е основна предпоставка за пълното използване възможностите на машинния агрегат, за реализиране на максимална производителност и минимален разход на гориво за единица извършена работа. От това как ще бъде съставен селскостопанският агрегат /трактор-работна машина/ ще зависят неговата производитепност и разходът на гориво, т.е. неговата ефективност. Чрез правилното агрегатиране на машините и правилното съставяне на нормите се осигуряват основните условия за пълното натоварване на енергетичното средство /трактора/, при което се постига максимална производителност. При пълно натоварване на трактора относителният разход на гориво за единица работа е минимален.

Затова при агрегатирнето на земеделските машини да се спазва условието: теглителната сила на трактора, взета с един коефициент на запас, да бъде равна на теглителното съпротивление, което оказва земеделската машина в работа при определени условия, т.е.

$$Pm.Km = R_M \qquad (2)$$

където *Pm* е теглителното усилие на трактора на теглича, кг; R_M - теглителното съпротивление на работната /прикачна/ машина, кг; *Km* - коефициентът за използване на теглителната сила на трактора /на запас/: при оран от 0,90 до 0,93 и при останалите видове работа от 0,94 до 0,96.

Определяне на теглителното съпротивление

Според някои автори (Цонев, Н., и др. 1987) за почвообработващи операции може да се приемат средни стойности (Таблица 1) при средни стойности на почвеното съпротивление:

Това са приблизителни средни стойности и без да са отчетени специфичното съпротивление на почвата и дълбочината на обработка.

Други автори (Иринчев, Д., 2013) дават по-пълна информация относно теглителното съпротивление и теглителната мощност но и тук не може да се каже как се променят тези параметри при всички почвени условия.

Необходимо е да се обвържат всички параметри и да се даде тяхната графична интерпретация както ще бъде след обосноваване на всеки един от тях.

Таблица 1. *Специфично съпротивление на някои селскостопански машини*

№ по ред	Машини	Стойности, kN/m
1	Брани зъбни	0,5-0,7
2	Култиватори за слята обработка на почвата	1,4-2,4
3	Валяци гладки	3,5-5,0
4	Култиватори за окопаване	1,2-2,6
5	Двустранни култиваторни лемежи	4,0-6,0

Определяне на работната ширина

Работната ширина на машината за обработка на почвата трабва да бъде правилно обоснована, тя зависи от междуредовото разстояние на обработваната култура и защитната зона от центъра на реда до края на обработваната ивица при трайни насаждения и при окопни култури, и от възможностите на трактора при обработка на освободени площи.

Определяне на дълбочината на обработка

Дълбочината на обработка зависи от изикванията на насаждението от една страна и от възможностите на трактора и специфичното съпротивление на почвата от друга страна. Голямата дълбочина на обработка може да причини повреда на кореновата система на разстенията но може и да стимулира образуване на дълбока коренова система при някои овощни видове. Отстраняването на корени които са на повърхността на почвата така наречените росни корени се оказва благоприятно и стимулиращо за развитие на корени на по-голяма дълбочина и подобряване на цялостното състояние на насаждението. Когато не е необходимо съобразяване с насаждение тогава се има предвид коренообитаемият почвен слой на културата която предстои да се отглежда.

Имитационно моделиране на параметрите на прцеса на почвообработка при фиксирана теглителна сила

Параметрите на процеса на почвообработка: работна ширина на машината, работна дълбочина на обработка, теглителната сила която трактора може да реализира на теглича и специфичното съпротивление на почвата са в пряка зависимост помежду си. За да се представи тази зависимост е формулирана на функционална връзка представена с формула 3 Съпротивлението на машината R_M, *кН/см*^{2} се получава като произведение на работната ширина, работната дълбочина, специфичното съпротивление на почвата то трябва да бъде по-малко или равно на реализираната от трактора теглителна сила формула 2.

$$R_M=ABC \qquad (3)$$

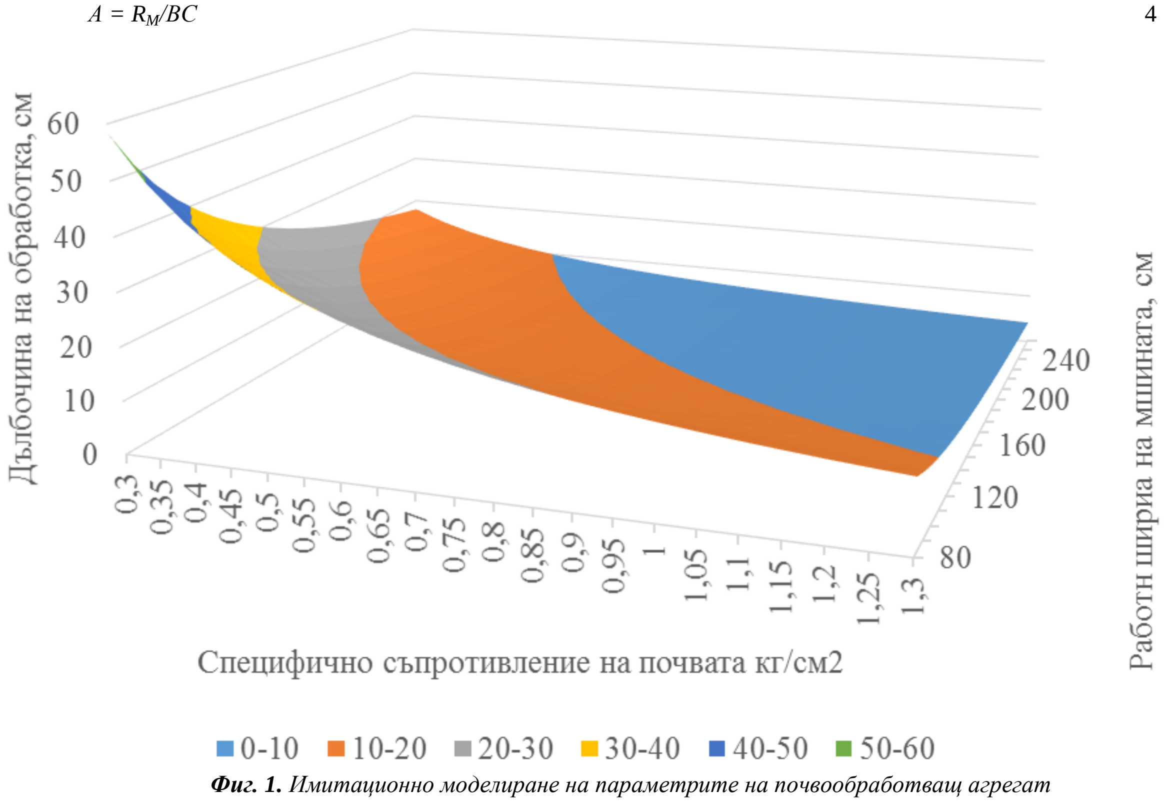
Където *A* е дълбочината на обработка, *см*;

B – работната ширина на машината, *см*;

C – специфичното съпротивление на почвата, *кН/см*^{2}.

Формула 3 може да се ползва за намиране на някой от четирите неизвестен параметър при известни отстаналите три. Чрез преобразуване на формула 3 с цел определяне на дълбочината на обработка се получава формула 4. Във формула 4 е фиксирана теглителната сила която може да реализира трактора. Това е най-често срещаният случай тъй като в нашата страна всеки земеделски стопанин разполага с универсален трактор от клас 1,4, ако задачата е намиране на оптимален трактор за стопанството задачата би изгеждала по друг начин. Специфичното съпротивление на почвата зависи от почвения тип, работната ширина и работната дълбочина на машината може да се променя.

$$A = R_M/BC \qquad (4)$$



Фиг. 1. *Имитационно моделиране на параметрите на почвообработващ агрегат*

На фиг. 1 са представени комбинации от параметри на почвообработващ агрегат съставен от трактор - клас 1,4 и почвообработваща машина при работа върху почви с различно почвено съпротивление. На графиката са обособени зони на възможни дълбочини на обработка. При леки почви с малко почвено съпротивление са възможни както по-големи дълбочини на обработка така и по-голяма работна ширина на машината и обратно при тежки почви с голямо почвено съпротивление са възможни както по-малки дълбочини на обработка така и по-малка работна ширина на машината. Чрез фиг.1 може да се проектира почвообработващ агрегат съобразно условията в които ще работи и съобразно технологията на отглежданата култура.

Изводи

1. За получаване на качествена продукция от земеделските култури е необходимо да се подържат благоприятни условия за тяхното развитие а това се постига чрез поддържане на почвената повърхност чрез почвообработки.
2. Обработката на почвата е сложен проблем, за който има много решения той е обект на много изследвания и не може да бъде решен еднозначно, необходимо е да се вземат предвид всички особености на отглежданите култури, технологиите на отглеждане, природни, почвени и социални фактори и да се избере подходяща технология и машина за поддържане на почвената повърхност съобразно конкретните условия и да отговаря на нуждите на земеделските производители.
3. Поради голямото разнообразие от почвени условия в нашата страна е целесъобразно да се ползва разработената зависимост между параметрите на почвообработката и почвеното съпротивление, така ще се получи правилно агрегатиране и от там висока ефективност на операцията.

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13. Soil Tillage in Agroecosystems

Efficiency of irrigation in growing tomatoes in greenhouse conditions

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Abstract*: Irrigation plays a key role in growing vegetable crops. The efficiency of irrigation is expressed in obtaining optimal yields in terms of quantity and quality. The use of water resources should be water and energy saving in order to reduce the costs of vegetable production and to be environmentally friendly. The main criteria for assessing the effectiveness of irrigation are the total and additional net incomes. In order to meet the set requirements for irrigation, the best effect is obtained by applying drip irrigation. When growing tomatoes, the value of the irrigation system is redeemed in the first year for areas over 5 dka, for areas below 5 dka it takes 2 years. Drip irrigation of tomatoes has shown that the frequency and size of irrigation rates affect the weight, diameter and length of the fruit, their number and hardness.*
KEY WORDS: *TOMATO YIELD, GREENHOUSE PRODUCTION, DRIP IRRIGATION, TOTAL AND ADDITIONAL NET INCOMES, QUALITY OF TOMATOES*

1. Introduction

In the conditions of climate change and growing population, the cultivation of agricultural crops requires increased energy efficiency and environmentally friendly use of resources. Vegetable crops, in particular tomatoes, are grown mainly in greenhouse conditions due to the sensitivity of the crop to climatic, soil conditions and the availability of water resources. Irrigation plays a key role in increasing the amount of yield and its quality indicators. The application of drip irrigation provides the necessary amount of water for growing tomatoes and helps reducing water consumption. Furrow irrigation reduces yields due to longer inter-irrigation periods and longer periods of soil drought, respectively (Wang et al., 2007). Drip irrigation saves water consumption by up to 50% compared to furrow irrigation.

When growing tomatoes in greenhouses, irrigation is especially important due to the high temperatures in them and the lack of natural rainfall. The amount of irrigation water affects both the yields and the qualitative indicators of production (Dumas et al, 1994). The application of reduced or increased irrigation rates affects the development of tomato plants and, accordingly, the quantity and quality of yield.

2. Materials and methods

Drip irrigation systems are PE irrigation pipelines (irrigation wings). These pipelines take water from ground or underground distribution pipelines. Dropper holes are factory-installed along the length of the irrigation pipeline or are mounted on the hose, as the water supplied to the irrigation wings comes out in the form of drops from the dripper holes only in the root system of the plants. This technology allows the submission of the necessary irrigation standards with great accuracy, both in time and in the amount of water volume (Gadjalska at al, 2017).

Determining irrigation rates is possible through several basic methods. Depending on the specific experimental conditions, the irrigation rate can be determined by the weight-thermostatic method. In this method, a soil sample is taken the day before watering, its weight is measured, dried at 105 ° C, measured again and the difference in weight of the wet and absolutely dry sample is determined. The irrigation rate can be determined by means of class "A" evaporators installed in the greenhouse or by using soil moisture meters, reading moisture every 10 cm, at a depth of up to 60-80 cm.

When supplying irrigation water, it is possible to consider variants of experimental setting with increasing or decreasing irrigation norms. There are also options for irrigation with a fixed inter-irrigation period and you vary depending on the soil's water supply. Another variation of experimental formulation is to apply water deficiency during different stages of culture development. The aim is to determine the possibilities for reducing the irrigation norms for obtaining optimal yields in terms of quantity and quality.

3. Results

Experimental setting with varying frequency and amount of irrigation water.

It has been established that the irrigation rate and the frequency of its supply have a significant impact on the efficiency of irrigation water use. When using an evaporator to determine irrigation rates and apply different coefficients of the evaporator, the efficiency of irrigation water use increases with the increasing frequency of irrigation. With the same frequency of application of the irrigation rate with increasing its amount, the efficiency decreases.

As the frequency of watering increases, the yields, the number of fruits, the total content of soluble substances, and the hardness of the fruits increase. As the amount of irrigation water increases, the number of fruits, the average weight of a tomato, and the length and diameter of the fruit increase, but the total content of soluble substances and the hardness of the fruit decrease (Hao et al., 2013).

Increasing inter-irrigation periods combined with decreasing irrigation rates impair the quantity and quality of yield (Zhai et al., 2010).`

Experimental setting with varying irrigation rates depending on the stage of development of tomato plants.

When applying water deficiency in different phases of plant development, it was found that it has a significant effect on yield during flowering and fruit formation, in contrast to the stage of fruit ripening. Compared to the submission of the full irrigation rate, the reduction of yields is in the range of 16-24% and 30-40%, respectively, in mild and moderate water deficit in the phase of flowering and fruit formation. In the phase of fruit ripening, the efficiency of irrigation water use increases with increasing water deficit (Li at al., 2022).

The application of full irrigation or a slight deficiency during the flowering and fruit formation phase is crucial for yield (Liu at al, 2019). It has been found that water deficiency has a significantly more adverse effect on yield in the flowering and fruit formation phase than in the fruit ripening phase. Irrigation water - the efficiency of use is highest when the level of irrigation is 70-90% in the phase of flowering and fruiting and 40-60% in the phase of fruit ripening (Buttaro et al., 2015)

Determining the efficiency of irrigation water use

The efficiency of irrigation water use is defined as the ratio between relative yields to the irrigation rate.

$$IWE = \frac{Y}{I}$$

where: *IWE* is the efficiency of irrigation water use

Y – yield [kg/dka]

I – irrigation rate [m^3/dka]

Criteria for irrigation efficiency

The main criterion for assessing the effectiveness of growing a crop is the total and additional net income from irrigation. The payback period of the capital investments for irrigation equipment is an additional criterion that guides the producers for how long the investments for the new irrigation equipment will be repaid.

Total net income is calculated by the following formulas:

ЧДо = Ц х Д – Рнап ,

Where: *ЧДо* is total net income, [lv/dka];

Ц – price of the production, [lv/kg];

Д – yield by irrigation, [kg/dka];

Рнап - costs of growing the crop under irrigation, [lv/dka].

The costs for growing crops under irrigation are determined by the following formula:

Рнап= Росн / F + Ренер +Ртех + (Рпол х N),

Where, *Росн* is the main cost of growing the crop, [lv/dka];

F - the total amount of the actually irrigated area, [dka];

Ренер - energy costs for water pumping, [lv/dka];

Ртех - depreciation costs of irrigation equipment, [lv/dka];

Рпол - labor costs for one watering, [lv/dka];

N - number of waterings.

The additional net income from irrigation, which is the main criterion for the efficiency of growing crops under irrigated conditions, is determined by the following formula:

ЧДоп = Ц х (Д - Дс) –(Рнап – Рс)

Where, *Чдоп* is additional net income from irrigation, [lv/dka];

Рс - costs of growing the crop without irrigation, [lv/dka];

Дс - yield without irrigation [kg/dka].

In order for a crop to be irrigated effectively, both total and additional net income must be positive.

4. Conclusion

The application of drip irrigation has the best effect on the amount of yield and its quality indicators. The technology provides both energy efficiency and water saving, which is especially important in the context of climate change.

The application of reduced irrigation norms would lead to additional savings of water and energy resources, without leading to a significant reduction in yields. It is extremely important that the application of reduced irrigation rates is in accordance with the stages of plant development.

Inter-irrigation periods and the size of irrigation norms have an impact on the quantity and quality of yield. It is not recommended to apply large inter-irrigation periods with reduced irrigation rates.

The use of objective criteria to assess the efficiency of irrigation water use and irrigation efficiency allows to determine the optimal conditions for growing tomatoes in greenhouses.

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Factors determining the quality of main and pre-sowing treatment of tomato growing soil

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Summary: *This is a review of the groups of factors influencing the quality of the main and pre-sowing tillage of the soil for growing tomatoes - soil-climatic, technological.*
The paper performs an analysis of the a priori information and from the conducted experimental researches the connection between the separate factors and the quality for performing the basic and pre-sowing treatment of the soil for growing tomatoes was established.
KEY WORDS: *TOMATOES, TREATMENTS, FACTORS INFLUENCING TREATMENTS.*

Introduction

Tomatoes are the most important vegetable crop in Bulgaria. To obtain good results from the production of tomatoes, an essential factor is tillage. Tillage is a basic and effective way to create favorable conditions for the growth and development of tomato plants. Its main task is to improve the water-physical parameters of the root layer, ie. creating optimal density, hardness, porosity, water permeability and favorable environment for all processes during the growing season.

Objectives of tillage

Tillage improves the nutritional regime by creating conditions for better burial of plant residues, organic and mineral fertilizers, intensive microbiological activity and mineralization of organic matter.

Tillage is also a way to control weeds, pests and pathogens. It completely destroys growing weeds, suppresses perennial weeds and slows the germination of weed seeds from the entire arable layer, many of which die before they reach the soil surface.

Types of processing

The different types of tillage: turning, loosening and mixing of the arable layer, compaction and leveling of the soil surface are performed with different tillage methods - plows, cultivators, harrows, cutters, rollers, etc. during the different ways of tillage - plowing, loosening, disking, harrowing, rolling, etc.

Factors determining quality and results

The quality of the various of soil cultivation depends mainly on several groups of factors, soil and climatic conditions, technical and organizational.

An analysis of the a priori information was performed in the paper and through the conducted experimental researches the connection between the separate factors, the quality and the costs for carrying out the main and pre-sowing treatment was established.

The technical factors on which the quality of the various tillages depends are mainly related to the tillage methods.

The form of the plow and its technical serviceability are important for quality plowing. The choice of a plow with a certain number of plow bodies, with front plow, with a suitable shape and length of the the throwing board, etc. are correlated with the tasks that are set with plowing. When plowing soils with a light mechanical composition, a plow with a front plow is used for better burying of post-harvest residues and turf. Cereals are a good precursor to field tomato production, but vegetable areas are rarely used for these crops. When plowing heavy soils, very dry, with high stubble left and highly developed weeds, the use of a plow does not give satisfactory results.

The plow must be in good technical condition before work. All plow bodies should have the same shape and working width, sharp plowshares, well-sharpened knives, good condition of the regulating mechanisms, the machine, etc.

The plow must be properly aggregated to a tractor with a certain power in order to be able to work at a speed of 5-6 km / h. Some acceleration to 7-7.5 km / h leads to less energy consumption and improves the quality of plowing.

For quality plowing, the plow must be pre-adjusted on the work site so that all plow bodies lie on a horizontal plane. Adjusting the plow in this way ensures the same plowing depth.

Depending on the tasks that are solved with cultivation, the type of cultivator is chosen. For fused cultivation it is best to use mounted cultivators with universal bodies.

In order to ensure fuller pruning of the weeds and better loosening of the soil, the working bodies of the cultivators must be of suitable shape, well sharpened and arranged in a checkerboard pattern in two rows, providing an overlap of 2-3 cm between neighboring working bodies. For quality cultivation it is necessary that the distance between the working bodies is approximately equal to its depth, or the ratio of the distance to the depth is 1: 1.5. Quality till with a cultivator is achieved when working at a speed of 6-8 km / h.

For quality disking it is necessary to choose suitable spherical disks with pointed edges, well sharpened and properly adjusted. To achieve the required depth, degree of fragmentation and mixing of the soil, the discs must be placed at an angle of 15-22 degrees to the line of movement.

The quality of tillage is significantly influenced by agro-technical factors. These include: the characteristics of tomatoes; the choice of predecessor and soil compaction after harvest; the quality of the previous treatments, the amount of plant residues, weeding of the areas and the different species composition of the weeds; fertilization and watering, etc.

Quality work with the tillage methods also requires preliminary organizational work. T the most important of these are: the preliminary cleaning of the fields from plant residues, their removal or their preliminary fritter for easier plowing; consideration of the length and configuration of the field, the size of the field, the terrain of the area in which the field is located, the weeding of the fields with annual and perennial weeds, etc.

The main method of plowing is plowing the beds. That is why the correctly determined width of the bed and the straightness of the furrows are one of the important agro-technical requirements for plowing. The beds are plowed on the ridge and plowing on the ruin. When plowing a ridge between the two beds, and when plowing a ravine in the middle of the bed, unploughed areas are obtained, which requires additional labor and energy. This can be avoided by plowing on a ridge during the previous year and vice versa. This is more difficult to do, so more often plowing with different widths of the beds or perpendicular to the plowing of the previous year is practiced. In order to eliminate the shortcomings in the plowing on ridge and ruin, the choice of beds with different widths and alternation of the two types of plowing of the even and odd beds is most often practiced. In the case of figured plowing, which is less frequent, the width of the bed is 30-40 m in the middle of the field and it is plowed figuratively on the wide and narrow side of the block. Cultivation and harrowing require larger and wider beds, which are selected by an experienced operator.

Soil and climatic factors are of great importance for quality tillage. The annual amount and distribution of precipitation, as well as the average annual and monthly temperature are factors that determine the need for tillage and ways of performing it.

The technological properties of the soil have a significant influence on the quality of plowing: connectivity, plasticity, stickiness.

The ability of the soil to resist forces aimed at separating soil particles is its connectivity, and the ability of the soil to change its shape without breaking down into smaller particles determines its plasticity, while the ability of soil particles to stick to each other when moist, or to stick to other objects determines its stickiness.

Soil moisture is a particularly important factor that determines the quality of tillage. Very dry or too wet soil makes tillage difficult, increases energy consumption and reduces machine productivity. Plowing the soil is best done at a certain range of humidity, at which the soil is best crushed and does not offer much resistance. This condition is called physical maturity of the soil and represents 70-90% of OMC. In moister conditions, cultivators work better than disking machinery, as very moist soil sticks to them. Therefore, in early spring, cultivating the soil as pre-sowing soil preparation is preferable to disking. In dry spring, however, disking as a more productive agro-technical event is necessary. Research data on soil moisture determined before sowing tomatoes during a field experiment also show the advantage of cultivation over disking in wet spring / Fig. 1 /.

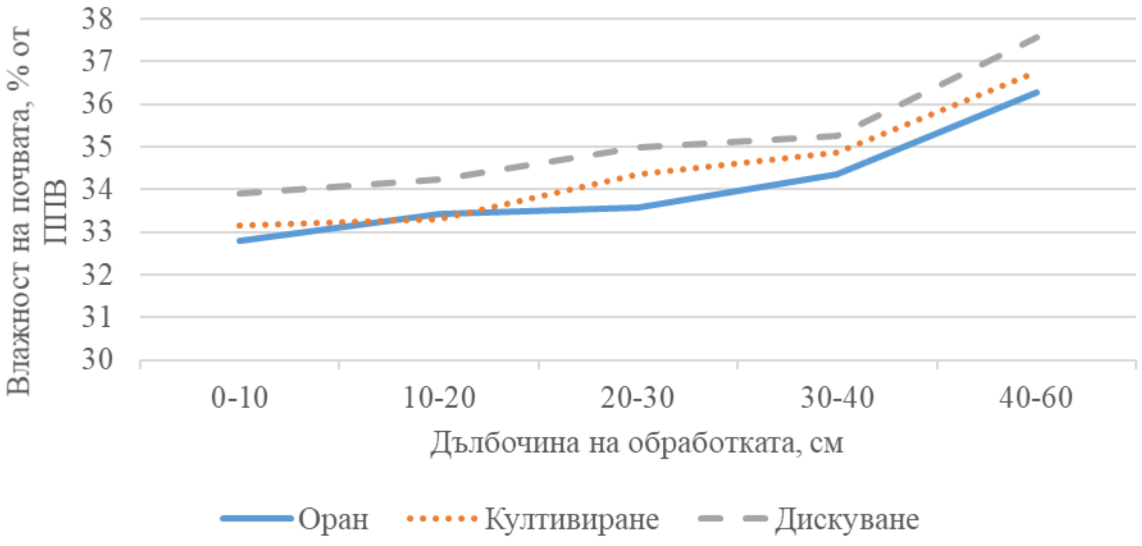

Fig. 1. *Soil moisture at different depths and types of tillage.*

Soil density and hardness are the main indicators that determine the requirements for tillage methods. The density of the soil changes more significantly until the sowing of the crops, while during the vegetation of the plants there is a certain equalization of the volume with the equilibrium density of the soil. The conducted research has established the optimal density for the cultivated crops - 1.0 - 1.4 g / cm3, its further increase above these limits hinders growth and development and reduces the yields obtained from them. From the tested different ways of tillage, a more significant compaction of the layer 0-20 cm is observed during disking compared to plowing / Fig. 2 /

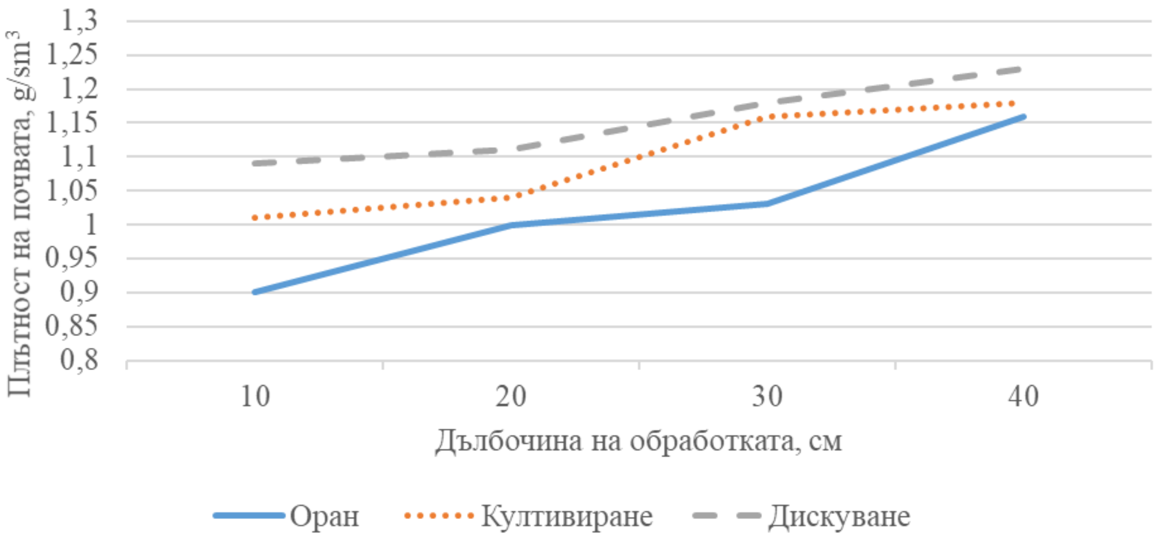

Fig. 2. *Soil density at different depths and types of tillage.*

Soil hardness expresses the mechanical resistance of the soil against the deforming effect of tillage methods, agricultural machinery, and plant roots. It varies from layer to layer and depends on soil moisture and density. The hardness of the soil, when tested with all three ways of tillage, is the highest in the variant with disking, followed by the variant with loosening, and the lowest is in the case of plowing / Fig. 3 /.

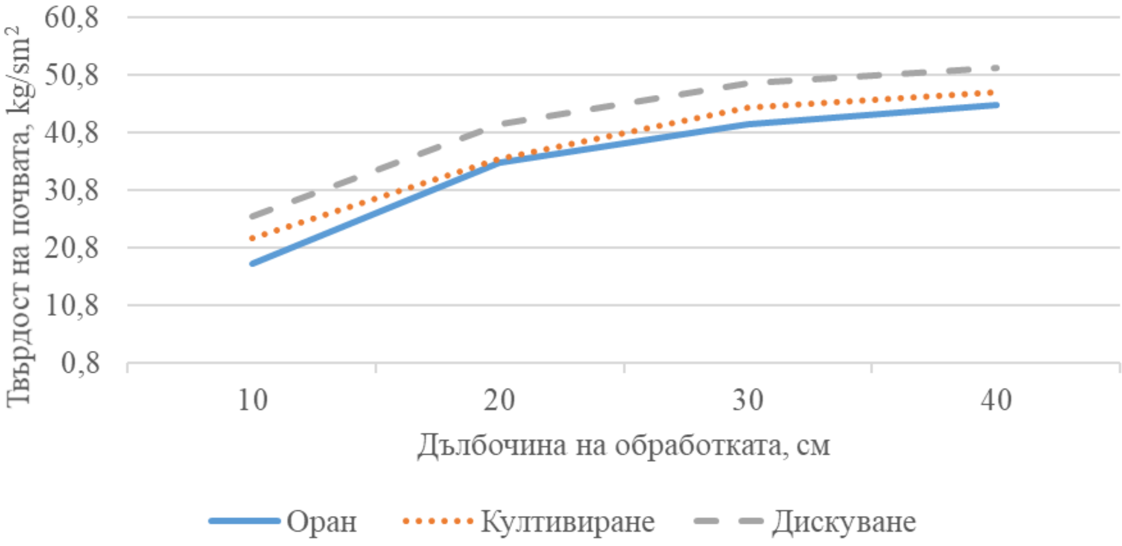

Fig. 3. *Soil hardness at different depths and types of tillage.*

Conclusions

1. The factors that determine the need for tillage, and quality of execution are: Soil and climatic, taking into account the characteristics of different soil conditions and the average annual and monthly precipitation and temperature. Technological, determining the correct choice of tillage methods and their aggregation to tractors with the appropriate power. Agrotechnical, taking into account the requirements of the cultivated crop and the predecessor, as well as the presence of plant residues and weeding of the field with different species composition of weeds. Organizational, determining the proper organization of work and good preparation of the field for tillage.

2. The results of studies on soil moisture determined before sowing tomatoes during a field experiment also show the advantage of cultivation over disking in wet spring.

3. From the tested different ways of tillage, a more significant compaction of the layer 0-20 cm is observed during disking compared to plowing.

4. The hardness of the soil in the tested three of tillage is the highest in the variant with disking, followed by the variant with loosening, and the lowest when plowing.

Acknowledgments

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Hydrometric monitoring of rivers and canals-technological innovations

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Abstract:*The protection of soils and waters is an extremely important issue for humanity. The main task to be done by the scientific staff is to monitor and control the water quantities leaving the water management facilities. Measurements of kinematic quantities can be used not only for quantitative assessment of runoff, but also for verification of theoretically derived hydraulic dependency in different forms of water movement. They are the basis for experimental determination of a number of theoretically introduced coefficients measurement of the hydraulic quantities determining them. Hydro metric measurement of non-pressure currents is a specific activity that has gained wide application around the world. When determining the water quantities, observations of the river outflow are made, also the measured parameters can be used for other engineering tasks in the construction of hydro technical facilities.[1]*
KEYWORDS*: MONITORING, WATER MANAGEMENT FACILITIES, WATER QUANTITIES, CONTROL, SPEED-AREA, WATER LEVELS*

1. Introduction

The modern development of measuring technology provides solutions for automation and decisive increase in the efficiency of measuring methods. The proposed innovative solutions are accompanied by assurances, subject to certain restrictive conditions that may not always be provided. In other cases, these trade-offs are considered perfectly acceptable over the alternative of not being able to perform the measurement in any other way. These issues would not be particularly important when performing incidental measurements in connection with individual engineering tasks for the certainty of the decisions taken. However, for the systematic work of NIMH on the assessment of the available water resources in the country, the issue becomes important because it is related to the investment policy for equipment re-equipment of the entire system with proven measuring instruments superior in quality to existing equipment.[1]This report will focus on the innovative way of determining the water quantity of a water facility in the event of elevated water levels.

Fig.*1 "Measurement of water quantity with hydrometric system –OTT Qliner 2*

The measuring device is a small plastic boat type catamaran (with two connected hulls) in which are built all the necessary sensors to perform the measurements (Fig. 1) On board is built-in transmitter for wireless radio communication (Bluetooth) with digital four ultrasonic Doppler sensors are installed in the bottom of the boat to measure the depth of the current and the speed profile. The equipment is designed to perform all measurements from the surface of the watercourse, where the plastic catamaran is fixed in a floating state. the registration of the results is performed wirelessly through the remote digital recording device.2.

2. Measurement

The field measurement was performed using the OTT Qliner 2 system at the hydrometric station of the National Institute of Meteorology and Hydrology at the station №52800., places near the town of Gotse Delchev**.** Due to high water levels, the existing hydrometric bridge is partially destroyed and the water quantity cannot be measured by the traditional hydrometric propeller method, this difficult reason and the prevailing meteorological reasons, namely high water levels must be used innovation method The Acoustic Doppler Current Profiler is known as ADCP. The OTT Qliner 2 system calculates the water quantity by the standard method used to measure water quantities with hydrometric propellers, namely "speed-area".

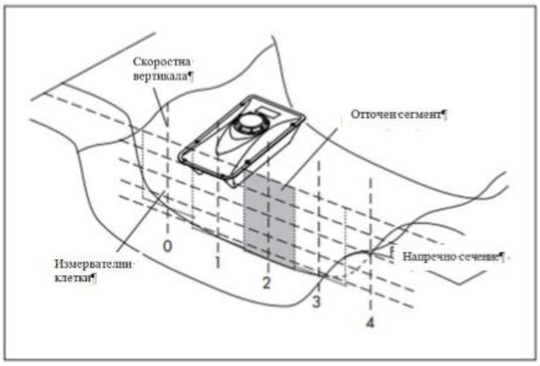

Fig 2 *Schematic diagram of water quantity measurement with hydrometric system "OTT Qliner 2" velocity-area*

The system uses Doppler sensors to read the depth of the current in a given vertical speed and respectively the speeds in a particular section**.** The hydrometric propeller - uses a rotating screw, which rotates from the current and is marked in rpm or speed - m / s, and a rod is used to measure the depths in the section**.** A cableway had been laid in advance, and the number and locations of the high-speed verticals had been determined. The measurement was performed by two operators, one positioning the boat in the speed valves and the other controlling the whole measurement process from the digital recorder (fig.1)

Fig.3 *Measurement of water quantity with hydrometric system –OTT Qliner 2 the station №52800, place near to Gotse Delchev*

Table 1: *HMS station№52800 , Momina Kula, calculation of the water quantity through the device software.*

```
Upstream_water_level:  0.00
Downstream_water_level: 0.00
Control_Text:  UNSP
NOTES

END NOTES
|
------------SUMMARY--------------
Edge_1:         1.00
Edge_1_Depth:  0.00
Edge_1_factor: 0.60
Edge_2:         32.00
Edge_2_Depth:  0.00
Edge_2_factor: 0.60

Position    0.000  2.000  4.000  6.000  8.000 10.000 12.000 14.000 16.000 18.000 20.000 22.000 24.000 26.000 28.000
Vertical        0      1      2      3      4      5      6      7      8      9     10     11     12     13     14
Mean_Vel.  -0.117  0.710  1.265  1.635  1.647  1.692  1.483  1.556  1.243  1.209  1.190  1.096  1.000  0.625  0.434
Depth       0.720  1.370  1.270  1.240  1.320  1.190  1.170  0.990  1.040  1.020  0.930  0.830  0.740  0.540  0.430
Q          -0.042  1.945  3.212  4.054  4.349  4.026  3.470  3.080  2.586  2.467  2.214  1.819  1.480  0.675  0.560
Edge_Q      0.000                                                                                                0.000

Total Q : 35.89 ±  0.35

------------DETAILS--------------

Start_Date/Time: 28/04/2022 16:27:20
```

Table2 *HMS station № 52800 r. Place, Momina Kula speed-area, calculation of the water quantity using Excel*

Vertical №	Distance m	Depth m	Area m^2	Velocity (average) m/s	Discharge m^3/s
Start point	0	0	0	0	0
2	2	1.37	2.74	0.71	1.945
3	4	1.27	2.54	1.265	3.213
4	6	1.24	2.48	1.635	4.055
5	8	1.32	2.64	1.647	4.348
6	10	1.19	2.38	1.692	4.027
7	12	1.17	2.34	1.483	3.470
8	14	0.99	1.98	1.556	3.081
9	16	1.04	2.08	1.243	2.585
10	18	1.02	2.04	1.209	2.466
11	20	0.93	1.86	1.19	2.213
12	22	0.83	1.66	1.096	1.819
13	24	0.74	1.48	1	1.480
14	26	0.54	1.08	0.625	0.675
16	28	0.43	0.86	0.434	0.373
End point	30	0	0	0	0.000
				Total Q	35.752

The result obtained from the subsequent processing of the measurement data is a coincidence of the results, the difference is a minimum of several liters, which is perfectly acceptable for the measurement conditions. The next Figure 3, show the water level.

Fig.5 *Shows the water level, H=136 cm*

2.1 Software, Diagrams.

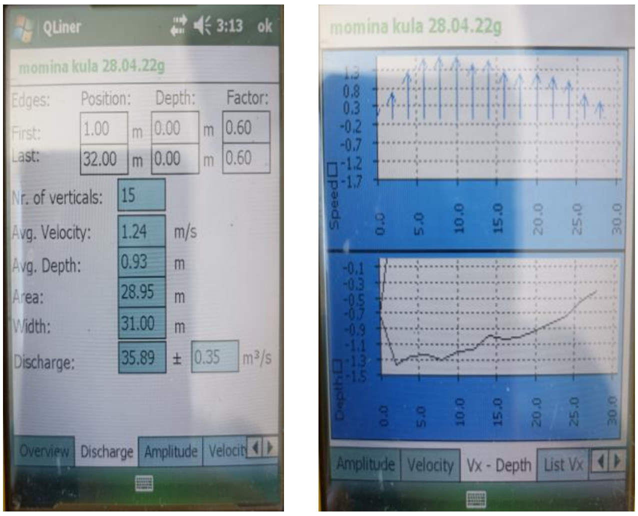

Fig.4 *Shows the discharge on the software, followed by processing.*

3. Conclusions

Advantage:

1. Significantly higher efficiency of measurement, in which with one positioning of the device digital and graphic information for the whole speed profile in the speed vertical is obtained.

2. Significantly shorter time for performing measurements at speed verticals and hence a significant reduction in the duration of the whole measurement.

3. Objective and clear idea of the distribution of vertical velocities, even during the measurement, which allows the detection of anomalous zones in the flow, making adjustments to the scheme of vertical velocities and reflecting them in the final result at the measurement site.

4. Possibility to apply the method to currents with depths in a large range of their change from 0.35 m to 10 m.

Disadvantages:

1. There is a limit on the depth of measurement of at least 0.35 cm, up to 10 meters;

2. The system cannot be used in very rough mountains

4.Literature

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