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Methodological approaches for the design of holistic crop growing technologies

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Summary. The article reveals the methodological approaches to the formation of holistic crop production technologies. It was formed: 1) an analytical scheme with the main connections and vectors for increasing the efficiency of using a quality indicator in the system of standardized raw materials and holistic Technology Transfer; 2) a logistic scheme concerning impact of the new organizational approaches on the effectiveness of holistic technology implementation; 3) a scheme for the system of interactions during transition to convergent technologies in the unit plant – diseases - pests. The issues are highlighted in the transition from level of discrete innovations to level of Technology Transfer. The correlation of winter wheat varieties in accordance with ecotypes in different agroecological zones of Ukraine is analyzed. The balance is noticed only for the forest-steppe ecotype (117.2%). The necessity of scientific support at a higher level is proved. On the example of the Center for scientific support of agricultural production in Kharkiv region and The Plant Production Institute nd. a. V. Ya. Yuryev of NAAS for the 10-year cycle (2006-2015) authors have showed that among the objects of intellectual property rights the share of holistic technologies equals close to 1%; the share of breeding and seed innovation is 63%. The evaluation of technological support for 13 winter and spring crops was carried out on the average number of technological operations. It is highlighted that the stage of care for crops is strategically important. Crops with significant integration in export and processing are more suitable for such an approach. On the example of soft winter wheat, a rank evaluation of 6 factors contributing to the implementation of productive and qualitative indicators was carried out. The respondents determined factors of fertilizers and weed control (1 rank) and lower positions for the total technological segment (3 ranks). In the system of preparedness for Technology Transfer, the respondents have analyzed levels of interest balance for 9 factors according to 6 vectors of innovation development in the crop sector. Authors have determined the leading factor is globalization (1 rank), and the least systematic one is the factor of consulting (6 rank). Information was received about the lack of holistic approach and an appropriate strategy adapted for different awareness of the methodology and mechanisms of Technology Transfer. The strategic significance of transition to the Technology Transfer level is substantiated.

Key words: technological operations, quality, a system of interactions, holistic technologies, balance of interests, Technology Transfer

INTRODUCTION

The technical support unit in the development and Technology Transfer for the crop growing has a leading value. On the one hand, the technical approaches are sufficiently worked out concerning tools, metrics and mechanisms of realization; on the other hand, there is poor systemicity in the formation of holistic technological solutions. The formation of holistic technologies on a modular principle is based on the determination and using of effective interconnections between different units on the basis of cross-cutting coordination. Hence, the effective use of the technical component requires taking into account many diverse factors. Globalization and integration into the international economic space clearly distinguish the transition to standardized raw material resources and zonal specialization. In these circumstances, the readiness of developers and users is quite different; it highlights the need for relevant research and analytics.

ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Under modern conditions agricultural production holds systemically the key position in the development of national economies (Rumf, *et al*., 2011). Global practical experience proves that with the use of modern innovative technologies, a sustainable agricultural production and broad integration with other industries is quite real (Shubravskaya, 2012, Makarov, 2009, Popovich, 2005, Tymchuk, *et al*., 2016). Instead, in Ukraine only at advanced farms, the genetic productivity potential implementation (GPPI) reaches 70-75% (Androsova, *et al*., 2007). In this regard, the introduction of holistic technologies is strategically important for Ukraine (Medvediev, *et al*., 2017, Kartashov, *et al*., 2012, Timchuk, *et al*., 2014, Zubets, *et al*., 2010). The organization and construction of effective technologies operates with multifactorial groups and must strictly adhere to the principles of interconnection both within between constituents and outside taking into account grouping with other areas of holistic technologies (Makarov, 2009, Tymchuk, *et al*., 2016). Instead, the technologies, which are basis for the modern crop growing focus mainly on productive indicators and do not meet fully the required complexity (Brovarets, *et al*., 2017, Zubets, *et al*., 2010, Goychuk *et al*., 2006, Masorenko, *et al*., 2006). In the current situation in the plant growing, the analysis of a system of interactions between different factors and its perspectives in relation to implementation of holistic technologies is relevant (Kartashov, *et al*., 2012, Tymchuk, *et al*., 2016).

OBJECTIVES

The purpose of the article is to determine the methodological patterns of the formation and evaluation of growing technologies and to analyze their efficiency in holistic Technology Transfer.

MATERIALS AND METHODS

The research was carried out in accordance with thematic plan tasks of The Plant Production Institute nd. a. V. Ya. Yuryev of NAAS during 2011-2017. The subject of the research was defined objects, zones and mechanisms in the system of holistic Technology Transfer. Technological support for 13 crops was analyzed. An existent status and prospects, structural and hierarchical system construction, formalization and systematic approach on the basis of cross-cutting coordination were taken into account in the development of working patterns. In the analysis, we used absolute and relative indicators, prognostication, table and graphical methods for presenting the results.

THE MAIN RESULTS OF THE RESEARCH

As a result of transition to production intensification, pragmatic attention to product quality has been increasing significantly. In early agro-phytocoenoses, close to natural ones, with low productivity and under conditions of limited consumption, a quality factor did not look like a strategic one, though it did not left out of attention indirectly. With expansion of the storage, processing, and growth of consumption, the quality factor is increasingly becoming the leading one for evaluation of product and technological parameters. The quality factor is the most important for formation of specialized markets, first of all, export and raw materials ones. At present, taking into account current realities and trends in Technology Transfer, there is strategic transition to assessing the quality factor as one of the leading and structuring factors. From this point of view a logistic scheme was formed to establish the main relations and vectors for improving the use of the quality indicator in the system of standardized raw materials and holistic Technology Transfer (Fig. 1).

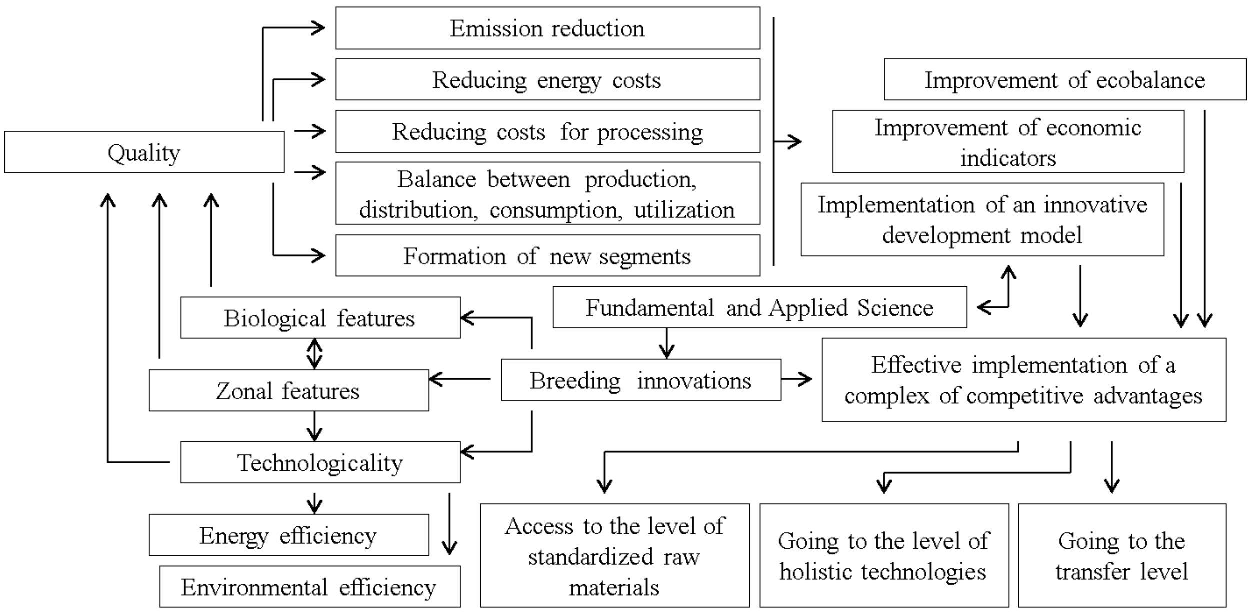

Fig. 1 Analysis of the main connections and vectors for increasing the efficiency of using the quality indicator in the system of standardized raw materials and holistic Technology Transfer

It is especially interesting and pragmatic from the point of view of constructing agronomic technologies close to convergent ones. With this approach we can study the interaction of Plant Growing, Processing, Energetics, Ecology, Environmental science and others in a single unit.

At the starting point we have selected the breeding innovations created in the system of fundamental and applied science. Such an approach is due to the fact that according to the analysis of the product segmentation of the Center of scientific support of agricultural production in the Kharkiv region for the 10-year cycle (2006-2015) among implemented objects of intellectual property rights, breeding achievements in crop growing made 63%; utility models amounted to 31%, the breeding achievements in livestock farming formed 3%, inventions made 3% as well; and the share of signs for goods and services was insignificant. In addition, among the utility models and inventions, the share of crop selection was also significant.

In particular, according to urgency of using in the life cycle of innovations, 31.2% of objects of intellectual property rights were realized during up to 3 years, 28.9% of them were implemented during from 3 to 6 years, 14%

of innovations were put into effect for from 6 to 10 years, 25.4% of objects were realized for over 10 years. That is, the general orientation towards the breeding discrete innovations in crop growing is traced quite clearly. In this case, the directions of biological and zonal features are mainly related to the system of testing and zoning and do not link enough with Technology Transfer. It is significant that the directions of technology, energy efficiency and environmental friendliness are not yet systemic and complex sufficiently. Instead, due to the quality factor, emissions might be reduced up to 15% and using nonrenewable mineral resources might be decreased by 8-10%. Higher quality of raw materials (concentration of key components, new quality) results in lower energy costs for processing, preparation, recycling, and utilization systematically due to more efficient processes (amilopectin and amylose starch, optimized fatty acid composition of oil, increased lysine content, etc.). From this point of view, the crop growing parameters become closer to industrial processing technologies; it allows approaching to technologies aimed at achieving high levels of quality as opposed to general orientation of the current technologies toward the productive parameters (Zubets, *et al*., 2010, Goychuk *et al*., 2006, Masorenko, *et al*., 2006). It affects the ecobalance automatically, improves economic indicators, and helps us to realize the existing competitive advantages more effectively through access to the level of Transfer, standardized raw materials and holistic technological solutions close to convergent ones (Yurchenko, 2011).

It is clear that such a large-scale task requires an absolutely different level of methodological support and organizational solutions, especially for state-owned research institutions. Significantly that the analysis of the model distribution of potential innovations by the type of their orientation on the example of The Plant Production Institute nd. a. V. Ya. Yuryev of NAAS has demonstrated that the share of technologies is less than 1%, and technological innovations act as elements of technology and "know-how". Such a situation reduces dramatically the potential of commercial using technologies as holistic objects of Technology Transfer and affects the level of agrarian production competitiveness negatively. The existing level of the genetic productivity potential implementation (GPPI) for the main crops equals less than 40-66% if the possible level is determined as 70%. It highlights the need of a new methodology for the formation of holistic technologies on the basis of cross-cutting coordination with the approach to the level of convergent ones.

In a generalized form, the new methodology and process of organization should take into account the strategic level of integration into the world's economic and scientific space through an effective system of realization for the complex of available competitive advantages and resources (Fig. 2).

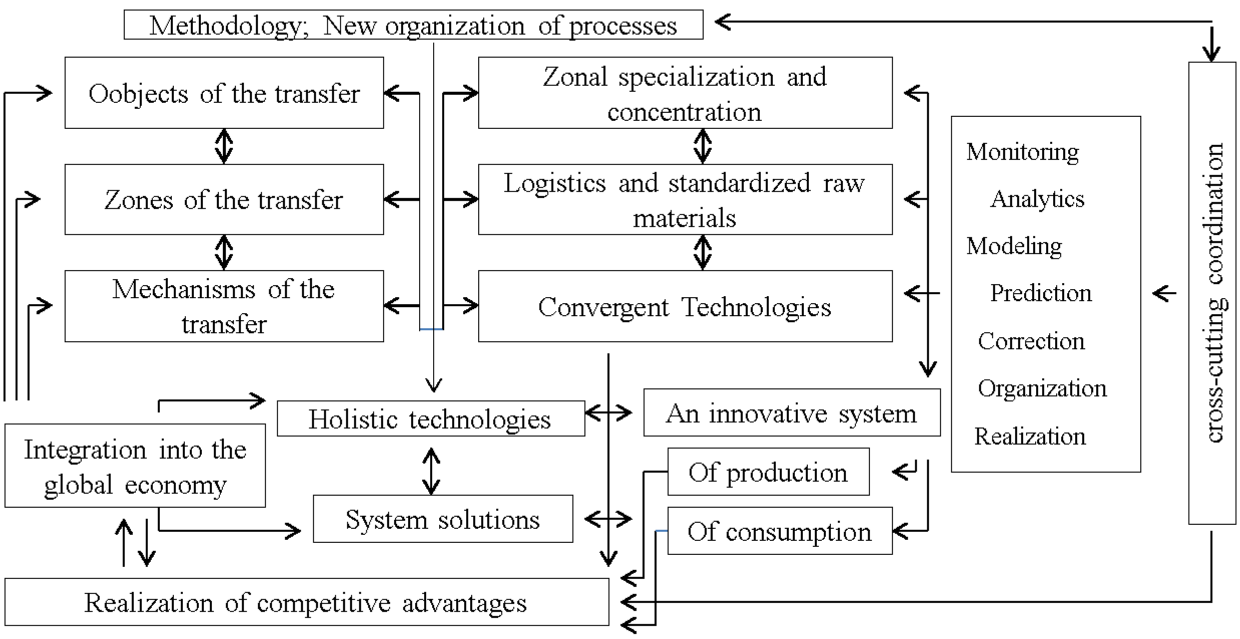

Fig. 2 Impact analysis of the methodology and new organizational approaches concerning the efficiency of the holistic technology implementation

In relation to Technology Transfer, objects, zones, and mechanisms should be defined. It is realized in zonal specialization and concentration of production, logistics, holistic approaches to the system of production and consumption through standardized raw materials and convergent technologies. Such an approach should be based on effective tools, reproducibility and monitoring mechanisms. From this point of view, through the principles of cross-cutting coordination, systematic monitoring (retrospective and ongoing), analytics of different levels, modeling, prediction, appropriate adjustment at the level of competitiveness, organization, implementation and control should be implemented systematically. Only under such conditions we might approach to an innovative system of production and consumption. Especially strategic thing is the innovative system of consumption, both as a motivator and as a relevant specialized market. Consequently, under current conditions, we systematically move to the validity of transition to the level of holistic technologies and system solutions.

In addition to the above, one should be aware of the essence and use the existing and potential systems of interactions between factors and groups of factors at the different organizational levels. For example, let's take a classic and typical crop growing unit plant-diseases-pests (Fig. 3).

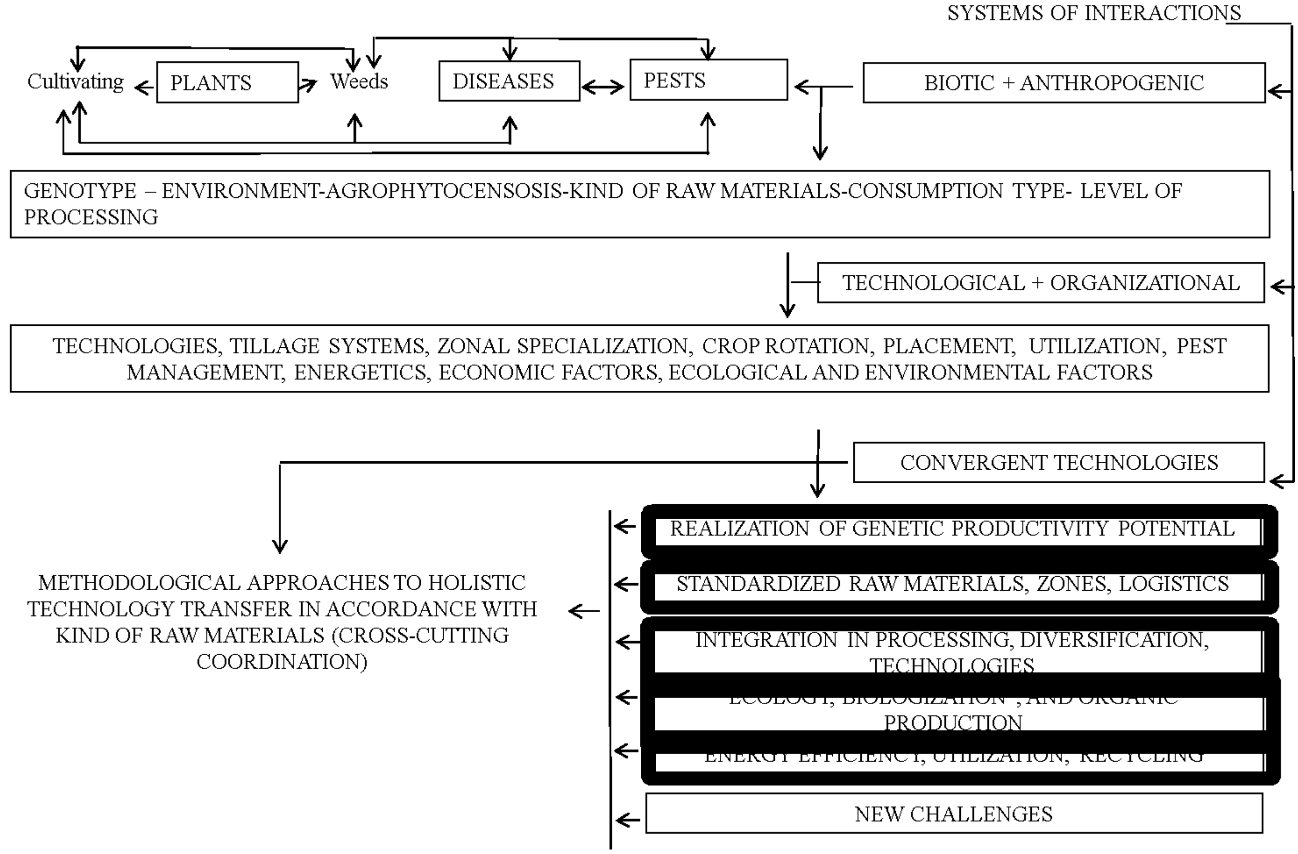

Fig. 3 Analysis of a system of interactions during transition to convergent technologies in the unit plant-diseases- pests

In turn, the plants should be divided into cultural crops and weeds. In the system of interactions we identified 3 standard levels: biological and anthropogenic; technical and organizational; convergent technologies. In the analysis, we used 2 levels of factors: 1) genotype – environment – agrophytocoenosis - kind of raw material - type of consumption - level of processing; and 2) technologies, tillage systems, zonal specialization, crop rotation, placement, utilization, pest management, energetics, economic factors, ecological and environmental factors (Fesenko, *et al*., 2017).. The first level was more generalized; and the second level was more detailed. Such an approach should be accompanied with the necessary level of formalized and effective metrics supplemented mandatory digital expression. At the level of convergent technologies for the development of methodological approaches to holistic Technology Transfer according to kind of standardized raw materials and on the basis of cross-cutting coordination, units were identified, which such approaches are worked out largely for. An exception is a unit of new challenges. The presented approach fits logically enough the modular model of holistic crop growing technology formation (Timchuk, *et al*., 2014), including a unit of phytosanitary monitoring.

Regarding a unit of genetic productivity potential implementation (GPPI), it is necessary to indicate its systemicity and relevance as a marker for the effective use of breeding genetic, zonal, technological, resource and organizational components. For this unit at the Kharkiv region, a 69-year (1951-2016) GPPI monitoring for winter soft wheat was carried out, which demonstrated specific variations during the last 5 years (2012-2016). It was GPPI trend to decrease while in general according to the sample, GPPI trend was set to rise. At the same time, retrospective monitoring and normal distribution of the sample is crucial. As an example, we give the corresponding data on winter soft wheat, which has showed that within the framework of a multi-year representative sample (1801-2016 years) in the normal distribution, the ratio between years with a yield higher than average (50.1%) and below than average (49.9%) was close to 1:1. It was also found that for oilseeds (sunflower, soybean, rape) in Ukraine at normal distribution, the ratio between minimum (*min*), average($\bar{x}$) and maximum (*max*) yields was close to 75% -100% -125 % (algorithm +/- 25). That is, the detection of existing patterns and modeling on this basis of relevant processes look quite pragmatic. To confirm the insufficient level of taking into account existing trends and regularities, we will refer to the analysis of the ratio of winter wheat varietal crops by ecotypes and agroecological zones in Ukraine (Table 1).

Table 1. Analysis of the ratio for winter wheat varietal crops by ecotypes in different agroecological zones of Ukraine

Ecotype of the variety	Existing ratio of varieties by ecotype, % (A)			Science-based ratio of varieties by ecotype, % (B)			Averaged ratio of varieties by ecotype A / B, %
	Agroecological zones			Agroecological zones			
	The steppe	The forest-steppe	Polissya	The steppe	The forest-steppe	Polissya	
Steppe	56.6	15.0	5.3	90	30	20	54.9
Forest-steppe	32.5	66.5	65.1	10	70	60	117.2
Western European	10.9	18.5	29.6	0	0	20	295.0

Considering that the variety (variety ecotype) is an important part of the varietal and integral technologies. The scientific substantiation (analysis and prognosis) and the actual manufacturing application of this trend are very important. At present, there is only a balance by the forest-steppe ecotypes (117.2%). But there is a significant imbalance by the steppe (54.9%) and western European ecotypes (295.0%) that can be considered as a one more argument of insufficient scientific support and the effectiveness of the equipped technologies. That is, from the methodological point of view, objects as well as zones and mechanisms of transfer are not effective enough, especially from the standpoint of the principles of cut-through coordination.

To prove this additionally, we can also provide data on the analysis of the equipped technologies by the average number of technological operations of 13 field crops (by 4 levels of resource support and a set of predecessors) (Table 2).

Table 2. Estimation of technological support of winter and spring crops by the average number of technological operations (calculated on the basis of data (Zubets, *et al*., 2010, Goychuk *et al*., 2006, Masorenko, *et al*., 2006)).

№	Crop	Technological operations $(\overline{x})$								
		altogether	Primary tillage		Seed-bad preparation and sowing		Crop management		Harvesting	
			pcs.	%	pcs.	%	pcs.	%	pcs.	%
Winter crop										
1	Winter wheat	28.81	4.75	16.5	5.93	20.7	11.06	38.5	7.00	24.3
2	Winter rye	25.25	3.00	11.9	6.25	24.8	8.75	34.6	7.25	28.7
3	Winter triticale	24.00	3.75	15.6	6.25	26.0	7.50	31.3	6.50	27.1
4	Winter rape	21.75	3.75	17.3	6.00	27.6	7.25	33.3	4.75	21.8
Spring crop										
5	Spring rape	21.75	3.75	17.3	7.50	34.5	5.75	26.4	4.75	21.8
6	Spring wheat	23.00	2.25	9.7	7.50	32.7	6.50	28.2	6.75	29.4
7	Spring barley	22.00	3.25	14.8	6.25	28.4	5.25	23.9	7.25	32.9
8	Buckwheat	21.25	2.00	9.4	8.00	37.6	5.00	23.5	6.25	29.5
9	Oat	20.75	3.00	14.5	7.00	33.7	4.00	19.3	6.75	32.5
10	Grain corn	21.25	3.50	16.5	7.75	36.5	5.75	27.0	4.25	20.0
11	millet	23.37	2.50	10.7	8.12	34.8	6.50	27.8	6.25	26.7
12	sunflower	23.75	4.25	17.9	7.25	30.5	8.00	33.7	4.25	17.9
13	Sugar beet	24.75	6.25	25.3	6.00	24.2	8.75	35.4	3.75	15.1

From the point of view of product quality assurance, the crop management is strategically important stage. This approach corresponds to a certain extent with winter crops, sunflower, sugar beets and partly corn, that is, those cultures that are more integrated into export and processing. In this case, relative to winter crops, such results can be explained by the prolonged period of vegetation. That is why a more effective approach is needed, especially from a methodological point of view, levels of assessment and balance of interests.

As the starting point we take the data of averaged multi-year particle of the factorial influence of weather conditions and 8 factor-elements of technology, which were obtained in the laboratory of crop production and variety studies of the Plant Production Institute nd. A. V. Ya. Yuryev of NAAS concerning soft winter wheat (Table 3). The share of weather effects was set by distribution at level of 10%. Although such indicator can only be correct for the scholastic regions, because the deterministic and transient effects of weather conditions are higher. It is enough to analyze the dynamics of the genetic productivity potential implementation (IGPP) and the variation coefficient of the yield indicator at the level of regions (over 37%). In connection with this, appropriate correction became essential. At the first stage, the share of weather effects was leaved unchanged. And in the network of the technology elements an attempt of adjustment was made. Taking into account the methodological non-workability of the approach formalized assessments were made (positive (+) and negative (-)) for improving the effectiveness of such an adjustment under assessments of agricultural production and science. The ranking was conducted in compliance with the sum of positive factors. The reconnaissance ranking showed that in compliance with gradation factors (factor impact on yield) first rank had factors of fertilizer and weeds control, and second rank had weather conditions. At the same time, the rank of the total technological segment had only third ranks. That is, it has been confirmed that at the level of developers and users technology are evaluated not as integral structures, but in compliance with their individual elements. In this case, there is a need to separate factors clearer as effective components of integral technologies. In this respect, the transition to multi-level and intersectoral structures is rather complicated. Therefore, the previously developed by us methodological approaches to the formation of integral technologies in concordance with modularity (Timchuk, *et al*., 2014) are rather relevant and pragmatic.

According to this approach, a ranking assessment of the balance of interests between developers, production, processing, consumers, utilization and national security of a number of factors was conducted (zonal specialization, point (discrete) innovations, technology transfer, transfer methodology, consulting, standardized raw materials, new organizational approaches, climatic transformations, globalization) in the system of transfer of integral technologies at the current level and near-term outlook (Table 4). It was quite anticipated that interests differed sufficiently, along with none of the factors was universal. That again confirms the relevance and pragmatism of methodological approaches to the formation of integral technologies under a modular basis. According to the aggregate estimate, the greatest challenges were globalization (1 rank), and the smallest was consulting (6 rank). Factors of climate transformations as in Table. 3 had 2 rank. The positive assessment of the factors of zonal specialization, standardized raw materials and new organizational approaches (2 ranks) is relatively encouraging.

Table 3 Analysis of the levels of estimation of factors contributing to the implementation of productive and qualitative indicators of soft winter wheat

№	Factor		Share factor impact %		Rating levels						% positive appraisals	rank
			Average	adjusted	Agroecology	Energetics	quality	consequences	competitiveness	controllability		
1	Weather conditions		10	10	+	+	+	+	+	-	83.3	2
2	Units of the technology	Term and quality of operations	4	5	+/-	+	+/-	+/-	+	+	66.6	4
3		Predecessor	10	10	+/-	+/-	+	+/-	+/_	+/-	54.5	6
4		Tillage	12	10	+	+	+/-	+/-	+	+	75.0	3
5		Fertilizers	17	15	+	+	+	+	+	+	100	1
6		Term and planting method	12	10	+/-	+	+/-	+	+	+/-	66.6	4
7		Variety and quality of seeds	8	9	+/-	+/-	+	+/-	+/-	+	60.0	5
8		Weed control	15	16	+	+	+	+	+	+	100	1
9		Pest and diseases control	12	15	+/-	+	+	+	+	+/-	75.0	3
Cumulative technological segment			90	90	+/-	+	+	+	+	+/-	75.0	3

Tab.4 Level analysis of the factor balance which contribute to the implementation of productive and qualitative indicators

№	Factors	Balance value						% positive appraisals	rank
		developers (science)	production	reprocessing	consumption	utilization	national safety		
1	zonal specialization	+	+	+	+/-	+/-	+/-	66.	2
2	discrete innovations	+	+/-	+/-	+/-	-	+	55.5	3
3	Technologies transfer	+/-	+/-	+	+/-	+/-	+/-	54.5	4
4	transfer methodology	+/-	+/-	+/-	+/-	+/-	+/-	50.0	5
5	consulting	+/-	+/-	+/-	-	-	+/-	40.0	6
6	standardized raw material resources	+/-	+/-	+	+/-	+	+	66.6	2
7	modern organizational approaches	+	+	+/-	+/-	+/-	+	66.6	2
9	climatic transformations	+	+	+/-	+/-	+/-	+	66.6	2
9	globalization	+/-	+	+	+	+/-	+	75.0	1

On the one hand, the obtained results confirm that working model is infallible, and on the other hand indicatively indicate the absence of a holistic approach and an appropriate strategy adapted for different levels of perception. In this respect, a significant role belongs to methodological support and information-analytical support. A rather important direction is the transition to scientific support on a commercial basis as an indicator of transition to a transfer level (Tsekhmeistruk, *et al*., 2017, Gutyanskyi, *et al*., 2016, Rudnytska, *et al*., 2017, Melnik, *et al*., 2017, Anikeev, *et al*., 2017). At present, working out the structure of modules and switching points is carried out. As a result of the obtained results approbation and approaches at the level of adjacent and non-adjacent industries the positive perception and the necessary level of universality for the formation of integral structures have highlighted, including technologies converging to convergent ones.

CONCLUSION

1. The acknowledgment of the relevance and effectiveness of the methodological approach of forming integral technologies according to the modular principle has been taken.

2. In the system of integral technologies formation for the crop industry, the quality factor and the level of standardized raw materials have been singled out as up-to-date.

3. The transition in the medium term from antagonistic to tolerant, and in the long-term - to a synergistic one is strategically important among factors for the effective use of scientific and agro-industrial production.

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Influence of some heavy metals on the organism of young pigs

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Summary. The results of studies related to the overdose effect of heavy metals, notably lead and cadmium, as well as their separate and the combined influence on the growth, development, productivity and hematological parameters of young pigs, are presented. It has been ascertained that heavy metals negatively affect the intensity of growth and development of the pig's body, which reduces the final animal's productivity. The live weight of pigs at the end of the experiment under the influence of heavy metals decreased by 2.8 - 5.5% compared with the control. There is the greatest negative effect was on animals which were fed only by cadmium. The overall increase in live weight of the experimental animals in comparison with the control also decreased from 2.8 to 6.05 kg, which is associated with various average daily gains in the groups. In the control group, this indicator was in the range of 550.79 g; under the influence of heavy metals, a decrease in average daily gains was observed in the range of 1.6-7.6%.

Along with a growth rate decrease of the experimental animals, their linear growth and physique changed. Animals that were given high doses of cadmium and lead in the food ration had lower indices of massiveness, compactness, wide-body and bone density, and the stretch index, on the contrary, slightly increased.
Under xenobiotics the morphological composition of the blood deteriorated significantly: the hemoglobin, total protein, albumin, and red blood cells decreased in the pigs' blood. Heavy metals significantly influenced the concentration of calcium and phosphorus in the blood, as well as their maximum decrease was when combined fed by toxic metals.

Key words: cadmium, lead, pigs, productivity, growth.

INTRODUCTION

Environmental pollution has now reached a catastrophic scale. This is mainly the result of the intensive development of industry, the irrational use of natural resources and the urbanization of society [1]. An important role in this process belongs to the excessive entry of chemical elements into the biosphere, which reflect the unfavorable ecological condition characteristic of many world countries [2, 3, 4].

Among the many environmental pollutants, heavy metals occupy a special place. Heavy metals are the conventional name for metals that have a density of more than 6g/cm3, a relative atomic mass of more than 50 a. m. u., most of which are toxic (zinc, cadmium, mercury, chromium, lead and others) [5]. There is also an opinion that these are metals also with atomic number 20 a. m. u. and more [6]. Of all the heavy metals, mercury, cadmium and lead are the most toxic to animals [7–9].

Intensive entry sources of these metals in the environment are the metallurgical and chemical industries, the combustion of solid and liquid fuels, pesticides, industrial wastes [10 - 14]. The entry of cadmium and lead into the environment annually increases, what result in the accumulation of these substances in soil, water, air, plant and animal organisms [1, 15, 16].
These elements are not liable to decomposition. Therefore, having entered the environment once, they continue to circulate in it. Migrating with underground and surface waters, heavy metals are absorbed by plants and enter the food chains of animals and humans [17, 18]. These elements have strongly pronounced toxicological properties, which are become apparent even at the lowest concentrations [19]. The mechanism of their toxic action is mainly due to:

1. a decrease in the enzymes activity
2. chelation and metabolic disorders
3. interaction with cell membranes and changes in their permeability and other properties.
4. competition with chemical elements that are vital for the body [20, 21]. In addition, these substances are easily absorbed and poorly excreted by the body, what results in their intensive accumulation in tissues and organs [22].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Research of many authors confirms that under the influence of heavy metals, the amount of total protein, albumin, globulins and other hematological parameters decrease [23, 24], which may indicate damage to the liver and blood-forming organs. Thus, the characteristic clinical display of the lead toxic effect is anemia, which is connected with porphyrin metabolic disorder and heme biosynthesis disorder, which speed up the destruction of hemoglobin and reduces its amount in the blood [25, 26]. With the introduction of excess amounts of cadmium, the metabolism of iron and copper is disturbed, the synthesis of hemoglobin is inhibited, the reserves of copper in the liver and other organs decrease sharply [24].

Thus, accumulating in the body of animals, disrupting metabolic processes, changing the enzymatic activity, heavy metals adversely affect the growth and development of animals, significantly affecting their productivity, degrade product quality, their chemical composition and biological value [27, 28,].

The reaction of animals to different toxicants and their concentration is ambiguous and depends on the species, age of the animal and other factors.

OBJECTIVE

In this regard, it was planned to investigate the effect of elevated concentrations of heavy metals (in particular, cadmium and lead), as well as the peculiarities of their separate and cooperative effect on the body of young pigs.

THE MAIN RESULTS OF THE RESEARCH

Studies were carried out on boars-neuter of a large white breed at the age of 3.5 months. The initial live weight was 30 kg. According to the principle of steam-analogues, 4 groups of 10 goals each were formed. The first group was the control. After a 15 - day levelling period, lead acetate was injected into the the pig feed of the second group at a dose exceeding the maximum permissible concentration in 10 times (50 mg / kg of feed); the third - cadmium acetate in a dose exceeding the maximum permissible concentration in the feed for pigs in 10 times (4 mg / kg of feed); the fourth is lead acetate (50 mg / kg of feed) + cadmium acetate (4 mg / kg of feed) (Table 1).

The main food allowance according to level of the energy nutrition and nutrients conformed to the norms. Extra nutrition was mixed manually with a small amount of concentrates, then with the main feed it was distributed to the feeders.

The growth and development of experimental animals was studied on the basis of the dynamics of their live weight, absolute and average daily gain, indicators of basic measurements and indexes of constitution. The physique indexes were calculated using special formulas. Store-cattle pigs were individually weighed every month, basic measurements were measured, on the 30th day of the study blood was collected from the tail vein for analysis, and the results of the studies were processed statistically [29, 30].

Table 1. Test circuit

groups	Number of animals, heads	Characteristics of feeding by periods	
		levelling period, 15 days	The main, upon reaching a body weight of 105-110 kg
I (control)	10	BD*	BD
II	10	BD	OP +50 mg/kg lead feed
III	10	BD	OP + 4 mg/kg cadmium feed
IV	10	BD	OP + 50 mg/kg lead feed + 4 mg/kg cadmium feed

Note: BD - basic diet*

When setting up for fattening, the live weight of the gilt did not differ by groups (Table 2). However, when removing animals from fattening, an intergroup difference was clearly traced, which was result of the influence of cadmium and lead salts. The smallest live weight when removed from fattening had gilt of the third group - by 5.87 kg (5.5%) compared to control, which indicates high toxicity of cadmium and its negative impact on the growth of young pigs. In turn, the animals of the second and fourth experimental groups also had a decrease in live weight in comparison with the control by 2.99 kg (2.8%) and 4.69 kg (4.4%), accordingly.

Table 2. Live weight of young pigs, M±m, n=10

Indicators	Groups			
	I	II	III	IV
Live weight when putting on the experience, kg	30,04±0,12	30,04±0,11	29,99±0,09	30,06±0,09
Live weight when removing from experience, kg	106,05±1,1	103,06±0,9*	100,18±1,2**	101,36±1,04 **
The total increase for the period, kg	76,46	73,66	70,41	71,31
Average daily gain, g	550,79±7,55	529,12±6,01 **	508,61±8,18 **	516,61±7,69 **

*Note: * - P>0,95; ** - P>0,99*

The overall increase in live weight of one animal during the fattening period was: in the control group - 76.46 kg, in the second group - 73.66 kg, in the third group - 70.41 kg and in the fourth group - 71.31 kg. The difference in total increments is due to different average daily gains in groups. In the control group, this indicator was within 550.79 g, in the second group it was 529.12 g, which was 3.9% (P> 0.99) less than the control group. The average daily increase in animals of the third experimental group was the smallest and amounted to 508.61 g during the fattening period, which was 7.6% less than the control indicator (P> 0.99). In animals of the fourth experimental group, the average daily gains for the fattening period also decreased and amounted to 516.61 g, which was less than the control by 6.2% (P> 0.99), but more than the third group, accordingly, by 1.6%.

Indicators of measurements of experimental animals at the beginning of the experience between the groups did not have significant differences and were in the control group at the level: body length - 74.04 cm, chest girth - 71.05 cm, height at withers - 39.18 cm and girth of metacarpus - 12.0 cm (Table 3).

Table 3. Basic measurements of experimental animals, M±m (n=10)

Basic measurements, cm	Опытные группы			
	I	II	III	IV
At the beginning of the experience				
Chest girth	71,05±0,06	71,04±0,07	70,8±0,15	70,9±0,12
Height at withers	39,18±0,11	39,13±0,09	39,0±0,11	39,05±0,12
snout-to-vent length	74,04±0,09	73,98±0,09	73,8±0,11	74,08±0,09
metacarpus girth	12,0±0,15	11,9±0,1	11,8±0,13	11,8±0,15
At the end of the experience				
Chest girth	118,6±0,4	116,0±0,28**	112,8±0,34***	113,8±0,31***
Height at withers	66,27±0,34	65,0±0,31*	63,3±0,35**	64,0±0,3**
snout-to-vent length	123,54±0,48	121,94±0,24**	117,8±0,37***	120,0±0,4***
metacarpus girth	18,33±0,29	17,9±0,19	17,2±0,26**	17,4±0,23*

*Note: * - $P \geq 0,95$, ** - $P \geq 0,99$, *** - $P \geq 0,999$*

At the end of the fattening, the animals of the control group had the following main measurements: body length - 123.54 cm, height at the withers - 66.27 cm, chest girth - 118.6 cm, metacarpus girth - 18.33 cm.

Measurements of the II, III and IV experimental groups of animals were less in comparison with the control group. Thus, the chest girth in these groups at the end of the experiment was less by 2.2% (P> 0.99), 4.9% (P> 0.999) and 4.0% (P> 0.999). The smallest indicators of measurements were the animals of the III experimental group - the height at the withers was 63.3 cm, the length of the body - 117.8 cm, and the metacarpus girth - 17.2 cm.

Changes in the measurements of the animals' body have affected the indices of their physique. Indices make it possible to more fully characterize the exterior features of animals, more accurately recognize the different degrees of underdevelopment.

Animals that received high doses of cadmium and lead with the diet had lower indices of massiveness, compactness, wide-body and bone density, and the stretch index, on the contrary, slightly increased (Table 4).

Table 4. The physique indices of experimental animals

Main indexes	Experienced groups			
	I	II	III	IV
At the beginning of the experience				
Massiveness	76,7	76,8	76,9	76,9
Stretch	188,9	189,1	189,2	189,6
Wide-body	181,3	181,5	181,5	181,5
Compactness	95,9	96	95,9	95,7
Index of bone	30,6	30,4	30,3	30,2
В конце опыта				
Massiveness	160	158,6	158,3	158,4
Stretch	186,4	187,6	186,1	187,5
Wide-body	178,9	178,5	178,2	177,8
Compactness	96	95,1	95,7	94,8
Index of bone	27,7	27,5	27,2	27,2

This can be explained by a certain short stature of animals from the experimental groups, which occurred as a result of the underdevelopment of animals under the influence of heavy metal salts. There is a decrease in the bones index of animals that consumed heavy metal salts. This can be explained by the negative effect of cadmium and lead on calcium and phosphorus metabolism in the body, and as a result, underdevelopment of bone tissue is observed.

It has been ascertained that the inflow of higher doses of cadmium and lead into young pigs affects the hematological parameters of the blood (Table 5). In all experimental groups, where heavy metals were fed to animals, in the doses prescribed by the methodology, hematological blood parameters deteriorated.

Table 5. Hematological blood parameters of young pigs, M±m, n=5

Indicators	Animal groups			
	I	II	III	IV
Hemoglobin, г/л	117,36±1,94	87,2±5,55*	90,42±0,6*	84,74±1,39*
Red blood cells, 10^{12}/л	8,26±0,13	7,28±0,06*	6,82±0,22*	6,5±0,12*
White blood cells, 10^{9}/л	8,38±0,24	7,08±0,15**	6,8±0,2**	6,3±0,09*
Albumen, г/л	40,72±0,66	35,44±1,39**	32,04±1,48*	28,84±1,1*
Total protein, г/л	76,22±0,71	68,3±1,29*	64,84±0,66*	63,90±1,42*

Note: * - P>0,999, ** - P>0,99

Thus, the amount of hemoglobin, red blood cells and white blood cells of the second pigs group decreased accordingly by 25.7% (P> 0.999), 11.8% (P> 0.999) and 15.5% (P> 0.99), the third group - by 22.9% (P> 0.999), 17.4% (P> 0.999) and 21.3% (P> 0.99), the fourth group - by 27.8% (P> 0.999), 18.8% (P> 0.999) and 24.8% (P> 0.999) in comparison with the control. There is also a decrease in the concentration of total protein and albumin, which may be a sign of liver damage. Against the background of the control group, the amount of albumin in the second, third and fourth experimental groups decreased by 12.9% (P> 0.99), 21.3% (P> 0.999) and 29.2% (P> 0.999), accordingly total protein by 10.4% (P> 0.999), 14.9% (P> 0.999) and 16.2% (P> 0.999).

It should be noted that a more intensive decrease in hematological parameters was in the fourth pigs group, in which cadmium and lead were feed to animals together.

The feeding of heightened doses of cadmium and lead is attended by a tendency to a decrease in the concentration of calcium and phosphorus in the blood of the studied animals (Fig. 1).

Thus, the content of calcium and phosphorus in the blood of pigs of the second group decreased by 22.8% (P> 0.99) and 49.6% (P> 0.90), accordingly. The concentration of calcium (P> 0.999) and 57% of phosphorus (P> 0.90) in the blood of the fourth pigs group decreased by 40%.

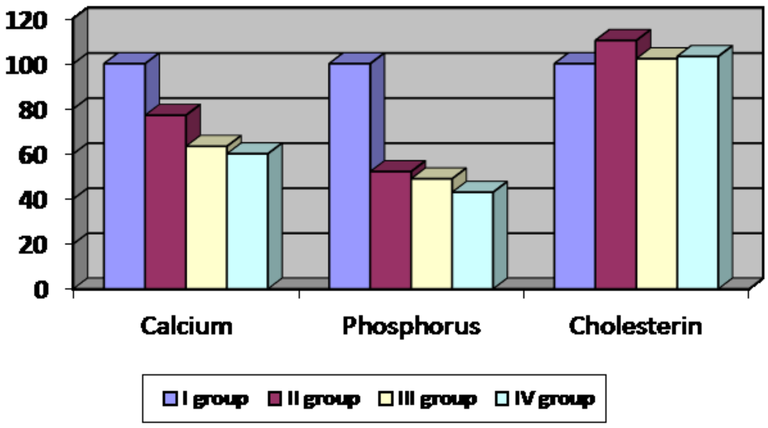

Fig. 1. The content of cholesterin, calcium and phosphorus in the blood of experimental animals, in % from the control

The content of cholesterin in the blood of pigs under the influence of heavy metals tends to increase, especially in animals of the second group. An increase in the second group of animals was by 10.3% compared with the control (P <0.90), in the third group by 2.2% (P < 0.90), in the fourth group by 3.2% (P <0.90).

CONCLUSIONS

The addition of cadmium and lead salts with diet feed of young pigs in doses exceeding their maximum permissible concentration in compound feeds by 10 times, has a negative effect on growth and physiological and biochemical processes in the body of young pigs and is attended by:

1. a decrease in growth activity, while the average daily gains for the whole fattening period decreased in the second group by 3.9%, in the third group by 7.6% and in the fourth group by 6.2% in comparison with the index of the control group. The growth impairment under the influence of heavy metals has affected the final body weight rates and has led to its decrease in the second experimental group by 2.99 kg, in the third group by 5.87 kg, in the fourth group - by 4.69 kg compared to the control. At the same time, the effect of cadmium was most noticeable. The combined effect of cadmium and lead on the growth of pigs was significant, but did not exceed the cadmium index, which may be due to the antagonistic interaction of cadmium and lead in the body of pigs.
2. heightened doses of cadmium and lead have affected the rate of basic measurements and body indexes. The smallest rate of measurements had the animals of the third experimental group, who were fed cadmium salts in high doses. Indices of massiveness, compactness, wide-body and bony tissue indices of the animals' body build under the influence of salts of heavy metals decreases, and the index of stretchiness increases slightly.

3. a decrease in the concentration of hemoglobin, red blood cells, white blood cells of the experimental pigs' groups, in comparison with animals of the control group. At the same time, there is a more pronounced intergroup difference for pigs that get cadmium and lead together. There is also the greatest negative effect of cadmium and lead on the hemoglobin content in the blood, especially in the second and fourth experimental groups.

4. a decrease in the concentration of total protein and albumin, which may be a indication of liver damage.

5. a decrease in the concentration of calcium and phosphorus in the blood of the studied animals.

6. a tendency to increase blood cholesterin.

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Complex driver movement mathematical model of the tractive rolling stock

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Summary. The paper developed a complex mathematical model of the rolling stock movement that takes into account the parallel operation of two real traction asynchronous engines of the first traction railway carriage and one equivalent engine of the second traction railway carriage of the diesel train in all modes of work, as well as the main types of oscillations of the train wagons, the forces distribution of interaction between them during the movement, as well as longitudinal and transverse elastic couplings of the wheel pair with the carriage of the car. In the article, the adequacy of the processes, resulting from three-dimensional modeling, processes occurring in the real diesel train DEL-02. On the complex mathematical model, were carried out tests on the effect of the main types of wagon oscillations to the motion and energy expenditure of a diesel train.

Key words: complex mathematical model, asynchronous engine, fluctuation of train carriages, diesel train.

INTRODUCTION

At present, a lot of mathematical models of DEL-02 diesel trains are known which make it possible to investigate and optimize the different modes of the train movement, the work of its traction asynchronous electric drives, as well as individual units and assemblies [1-6]. Most of the research is done on models that contain one or two equivalent traction engines and are described by systems of ordinary nonlinear differential equations that allow describing with sufficient accuracy the electromagnetic processes in the engines, the acceleration modes, the train motions over the distances with the known path profile and braking. In this case, the three-component rolling stock is represented as a single-mass or three-mass system [7, 8]. In the latter case, it is possible to investigate the forces acting between the wagons, as well as the longitudinal oscillatory processes between the wagons that can arise in the composition and lead to additional energy expenditure during the movement of the diesel train, and to the possible uncomfortable sensations for passengers. However, in the process of moving along the railway track, the rolling stock experiences more complex oscillatory movements, which are caused by uneven methods, the presence of gaps on the rail joints, the conicity of the rolling surface of wheel sets, and the presence of unevenness on this surface, the type of spring suspension and other factors. The mechanical vibration dampeners existing in the railway wagons, reducing the influence of dynamic influences and, the more so, to provide the smooth movement of the rolling stock, but these effects still lead to the fact that the carriages of the rolling stock are in an oscillatory state. In this case, each type of oscillation can occur separately or together with other types of oscillation. Based on this, a complex mathematical model, should take into account not only longitudinal oscillations, as well as other types of vibrations during the movement (transverse drift, wobble), and also take into account the longitudinal and transverse elastic bonds of wheel pairs of the railway wagons. In addition, the complex mathematical model should include variables that characterize both individual traction electric drives, as well as the parameters of the train itself, its components and force arising from the interaction of railway wagons during its movement. This, in its turn, makes it possible to parallel study of forces on a complex mathematical model, which exist between wagons, the causes of oscillations, their nature and mutual influence, as well as the influence of mechanical vibrations on electromagnetic processes in traction engines, determine the laws of optimal control, when solving the problems of costs optimization by rolling stock movement as well as to determine the conditions for the steady and safe movement of the train along railway tracks with irregularities. In addition, the complex mathematical model makes it possible to carry out the studies described above not only at the speeds of rolling stock that are currently accepted by the Ukrainian railways (up to 100 - 120 km/h), but also at speeds characteristic of high-speed traffic of trains, because constructively diesel train DEL-02 can reach speeds of up to 140 km/h. This makes it possible to clarify the results of studies of the parallel operation of traction motors, slipping processes, and wagon oscillations for increased train speeds. The latter is especially relevant in connection with the fact that the wagon fluctuations directly depend, on the one hand, from the speed of rolling stock movement, because with the increase in the route speeds of train traffic along the railway lines, the amplitude and frequency of oscillations can increase, and on the other hand, the quality of the railroad track, and the presence of unevenness on the surface of the railway track can results in the appearance of transverse oscillations.

PURPOSE AND TASKS OF RESEARCH

The aim of the article is to develop a complex mathematical model of the rolling stock movement that takes into account the parallel work of two real traction induction motors, the first traction wagon with engine and one equivalent engine of the second traction wagon with engine of a diesel train, in all modes of their work, as well as the main types of oscillations of the train wagons and the distribution of forces of interaction between them during the movement and transverse oscillations and wobble of wheel sets.

COMPLEX MATHEMATICAL MODEL OF DIESEL TRAIN MOVEMENT

For a complete and accurate description of the processes occurring on the diesel train during its movement, the mathematical model of the object should include variables that characterize not only the main types of wagon oscillations, but also individual traction electric drives, as well as the parameters of the train itself, its components and forces arising from the interaction of train cars in the movement process [9, 10]. In this connection, a complex mathematical model for the motion of a diesel train has been developed. This model simulates a rolling stock of three railway wagons (two motor railway wagons and one non-motorized) and takes into account the main types of oscillations of train wagons, the distribution of interaction forces between them and the possibility of slippage during the movement of the train. At the same time, the model uses real traction motors in the first railway wagon with engine and an equivalent traction engine in the second railway wagon wit engine. In the mathematical model of diesel train movement, two identical idealized models of traction asynchronous motors are used, and two models differing in parameters [9, 10]. This is due to the fact that on the real diesel train in each of the two engine-wagons and the mechanical parts of the two engines are not exactly the same, because in their production it is impossible to exactly observe the symmetry of the stator and rotor windings, the smoothness of the air gaps, the sinusoidal distribution of the magnetic streams and scattering fluxes, as well as losses in steel, from which engine components are manufactured.

The complex mathematical model can be represented by the following system of twenty-five ordinary nonlinear differential equations of the first order with six controls, and equations (2) - (5) can be written both through the flux linkages and through the currents of the motors:

$$\frac{dS}{dt} = k_1 V_1; \tag{1}$$

$$\begin{aligned}\frac{d\Psi^q_{\alpha 1}}{dt} &= b_1^q U^q_\alpha - a_s^q \Psi^q_{\alpha 1} + a_s^q k_r^q \Psi^q_{\alpha 2} = \\ &= U^q_\alpha - r_1^q i^q_{\alpha 1},\ q = \overline{1,3};\end{aligned} \tag{2}$$

$$\begin{aligned}\frac{d\Psi^q_{\beta 1}}{dt} &= b_2^q U^q_\beta - a_s^q \Psi^q_{\beta 1} + a_s^q k_r^q \Psi^q_{\beta 2} = \\ &= U^q_\beta - r_1^q i^q_{\beta 1},\ q = \overline{1,3};\end{aligned} \tag{3}$$

$$\begin{aligned}\frac{d\Psi^q_{\alpha 2}}{dt} &= -a_r^q \Psi^q_{\alpha 2} + a_r^q k_s^q \Psi^q_{\alpha 1} - \omega^q \Psi^q_{\beta 2} = \\ &= -r_2^q i^q_{\alpha 2} - \omega^q \Psi^q_{\beta 2},\ q = \overline{1,3};\end{aligned} \tag{4}$$

$$\begin{aligned}\frac{d\Psi^q_{\beta 2}}{dt} &= -a_r^q \Psi^q_{\beta 2} + a_r^q k_s^q \Psi^q_{\beta 1} - \omega^q \Psi^q_{\alpha 2} = \\ &= -r_2^q i^q_{\beta 2} - \omega^q \Psi^q_{\alpha 2},\ q = \overline{1,3};\end{aligned} \tag{5}$$

$$\begin{aligned}\frac{d\omega^q}{dt} &= \frac{p}{J^q}\Big(\frac{3}{2} p \frac{k_r^q}{\sigma^q L_s^q} \frac{i}{R^q}(\Psi^q_{\alpha 2}\Psi^q_{\beta 1} - \Psi^q_{\alpha 1}\Psi^q_{\beta 2}) - \\ &- a_0 - a_1\omega^q - a_2(\omega^q)^2 - \underline{i(S)} - \omega_r(S) + \\ &+ \eta^q_\delta(t)\Big),\ q = \overline{1,3};\end{aligned} \tag{6}$$

$$\begin{aligned}\frac{dV_1}{dt} &= \frac{1}{m_M}\Big(\sum_{q=1}^{2} \frac{3}{2} p \frac{k_r^q}{\sigma^q L_s^q} \frac{i}{R^q} \cdot \\ &\cdot (\Psi^q_{\alpha 2}\Psi^q_{\beta 1} - \Psi^q_{\alpha 1}\Psi^q_{\beta 2}) - F_{12} - F_{c1}\Big);\end{aligned} \tag{7}$$

$$\begin{aligned}\frac{dV_3}{dt} &= \frac{1}{m_M}\Big(\frac{3}{2} p \frac{k_r^3}{\sigma^3 L_s^3} \frac{i}{R^3} \cdot \\ &\cdot (\Psi^3_{\alpha 2}\Psi^3_{\beta 1} - \Psi^3_{\alpha 1}\Psi^3_{\beta 2}) + F_{23} - F_{c3}\Big);\end{aligned} \tag{8}$$

$$\frac{dV_2}{dt} = \frac{1}{m_T}(F_{12} - F_{23} - F_{c2}); \tag{9}$$

$$\frac{dF_{12}}{dt} = C_{12}(V_1 - V_2); \tag{10}$$

$$\frac{dF_{23}}{dt} = C_{23}(V_2 - V_3); \tag{11}$$

$$\begin{aligned}\frac{dQ}{dt} = g_1;\ \frac{dg_1}{dt} &= -\frac{2K}{m_{wp}} \cdot \frac{1}{V_2} g_1 - \\ &- \frac{2K}{m_{wp}}\varphi - \frac{2C_y}{m_{wp}} Q;\end{aligned} \tag{12}$$

$$\begin{aligned}\frac{d\varphi}{dt} = g_2;\ \frac{dg_2}{dt} &= -\frac{2Kl^2}{J_{wp}} \cdot \frac{1}{V_2} g_2 + \\ &+ \frac{2Klh_c}{J_{wp}R^4} Q - \frac{2C_x l^2}{J_{wp}}\varphi,\end{aligned} \tag{13}$$

where S is the distance that the diesel train passes and is counted from the start of the railway path; t is time; k_1, b_1^q, b_2^q, $a_s^q = \frac{1}{\sigma^q T_s^q}$, $k_r^q = \frac{L_m^q}{L_r^q}$, $a_r^q = \frac{1}{\sigma^q T_r^q}$, $k_s^q = \frac{L_m^q}{L_s^q}$, $\sigma^q = 1 - k_r^q k_s^q$, $T_s^q = \frac{L_s^q}{r_1^q}$, $T_r^q = \frac{L_r^q}{r_2^q}$, L_r^q, L_m^q, L_s^q, r_1^q, r_2^q ($q = \overline{1,3}$) are constant coefficients that take into account the variants of the two real processes of the first railway wagon with engine and one equivalent drive unit of the second railway wagon with engine; q is number of engines; V_1, V_2, V_3 are speeds of movement, respectively, of the first, second and third railway wagons of the diesel train (Fig. 1); $\Psi^q_{\alpha 1}$, $\Psi^q_{\beta 1}$ ($q = \overline{1,3}$) are the projections on the α and β axes of the stator flux linking, respectively, of the two real engines of the first railway wagon with engine and one equivalent drive of the second railway wagon with engine; U^q_α, U^q_β ($q = \overline{1,3}$) are projections on the α and β axes of the stator windings of the two real motors of the first railway wagon with engine and one equivalent drive unit of the second wagon with engine, respectively; $\Psi^q_{\alpha 2}$, $\Psi^q_{\beta 2}$ $(q=\overline{1,3})$ are projections on the axis α and β of the flux linkages of the rotor, respectively, of the two real engines of the first wagon with engine and one equivalent drive unit of the second wagon with engine; ω^q $(q=\overline{1,3})$ are angular rotational speeds of the rotors, respectively, of two real engines of the first wagon with engine and an equivalent second wagon with engine; p is the number of pole pairs of the stator of each motor; J^q $(q=\overline{1,3})$ is the moment of inertia of the engine and the mechanism, connected to the shaft, respectively, of the two real engines of the first railway wagons with engines and one equivalent drive unit of the second railway wagon with engines; i is reducer gear ratio; R^q $(q=\overline{1,3})$ is wheel radii correspondingly of the motor pair of the first wagon with engine with two real engines and one wheel pair of the second wagon with engine with one equivalent drive; a_0, a_1, a_2 are constant coefficients, are constant coefficients which characterize the load torque; $i(S)$ is function of resistance from the slopes of the path profile; $\omega_r(S)$ is resistance function from path profile curves; $\eta^q_\delta(t)$, $q=1,2$ is random function for simulate the possibility of slippage, $\eta^3_\delta(t)=0$; m_M, m_T are the weights of the wagon with engine and trailed railway wagons respectively; F_{12}, F_{23} are forces acting between the first and second the second and third wagons of the train respectively; F_{c1}, F_{c2}, F_{c3} are forces of resistance to movement of the first, second and third railway wagons respectively; C_{12}, C_{23} are elasticity coefficients between the first and second, and the second and third railway wagons; Q is the amount of lateral deviation (drift) of the wheel pair of the second railway wagon; g_1, g_2 are intermediate variables; K is creep coefficient; m_{wp} is mass of the wheel pair of the second railway wagon; φ is angle of waggling of the wheel pair of the second railway wagon; C_y, C_x are rigidities of transverse and longitudinal bonds respectively; l is half distance between wheels on the wheel pair of the second railway wagon; J_{wp} is moment of inertia of the wheel pair of the second railway wagon; h_c is conicity of the wheels of the second railway wagon; R^4 is wheel radius of the second railway wagon.

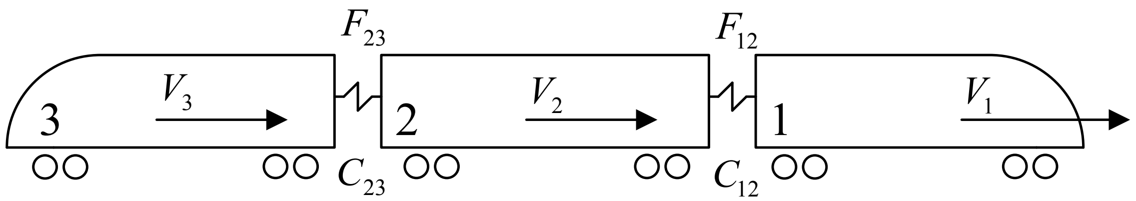


Fig.1. The speeds of movement of diesel train railway wagons, the coefficients of elasticity and the forces acting between the railway wagons

Model (1) - (13) includes: equation (1), which describes the distance that the rolling stock passes over the time interval of control; equations (2) - (6), describe the processes taking place in two real drives of the first railway wagon and the equivalent drive of the second railway wagon, while (2) - (5) simulate the main electromagnetic processes (via flux linkages or currents), and equations (6) – mechanical part of three traction asynchronous electric drives; equations (7) - (9), describe the speeds of three carriages of rolling stock; equations (10), (11) simulate the forces that act between the wagons of the train; (12), (13), describe the level of lateral deviation and the angle of waggling of the railway wagons wheel pair (Fig. 2).

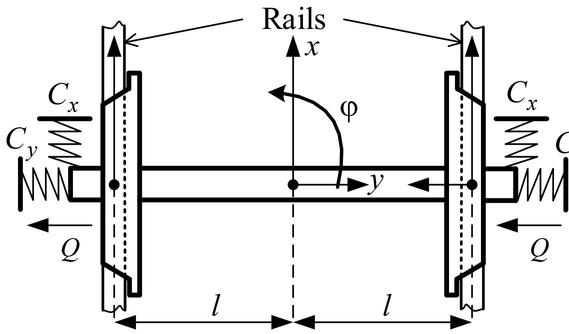


Fig. 2. Forces acting on the wheel pair, which is connected with the carriage by elastic bonds

Comparison of simulation results on the developed model with the results of experimental studies on a diesel train confirmed the adequacy of the obtained model. The complex mathematical model (1) - (13), unlike existing models with one equivalent traction drive, allows to simultaneously study electromagnetic and electromechanical processes of three diesel train engines simultaneously, simulate skidding of wheel pairs on any of the two engines of the first railway wagon with engine, and also determine the distance that the rolling stock passes during the control time. In addition, in contrast to models that take into account only the longitudinal oscillations of the train wagons [7, 8], model (1) - (13) also takes into account the oscillations associated with the lateral deviation of the diesel train wagons (transverse oscillations), as well as influence of wagons rolling stock wobble in the process of its movement over the railway path for the process of train engine work.

Using the model (1) - (13), several types of processes can be modeled:

1) acceleration of diesel trains, which, depending on the acceleration mode can last up to 100 - 160 seconds;

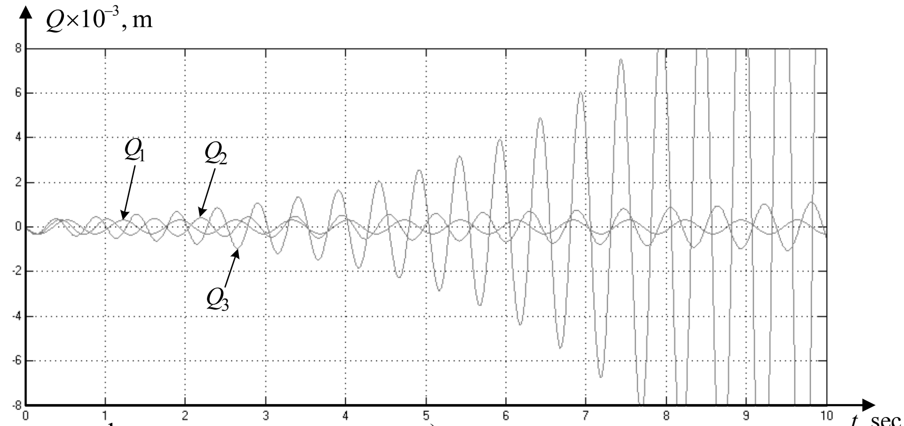
2) the oscillations of the diesel train wagons, the period of the oscillation, depends from the loading of the railway wagons and lasts to 80 seconds;

3) electromagnetic processes in the electric drive, where the frequency of the supply voltage can vary from the fraction of the hertz to 200 Hz;

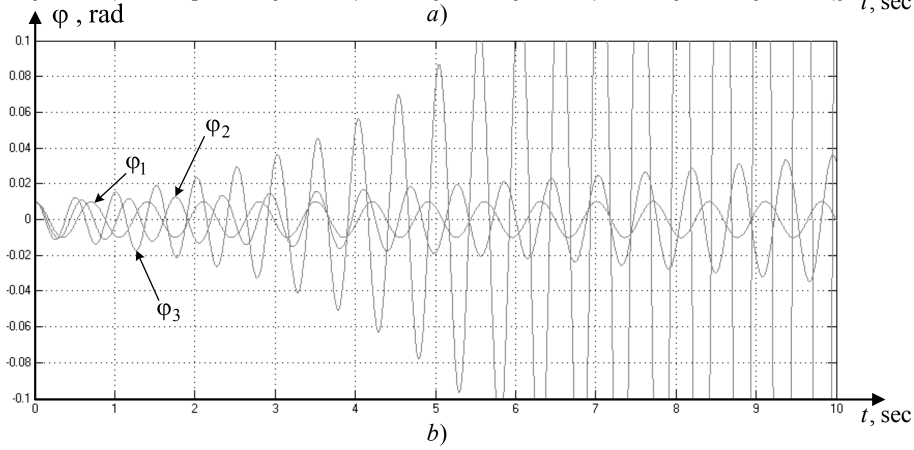
4) transverse oscillations of wheel pairs and their wagging, where the oscillation frequency is several hertz.

Since the time constants of different processes differ by orders of magnitude, the initial model does not make sense to use for the study of any processes, since this substantially increases the expenditure of computer time. The need for this model arose from the experimental trips of a diesel train at speeds exceeding 130 to 135 km/h, when there are quite strong transverse oscillations that could not be explained without simulating the movement of the wheel pair (Fig. 2) with the aid of relations (12) and (13).

Simulation (Fig. 3 - Fig. 6) was carried out with real parameters of the wheel pair of diesel train DEL-02. In Fig. 3 shows the curves of the lateral deviation Q and the angle of wagging φ of the wheel set of the wagon of the rolling stock during the passage of irregularities with the value of the initial deviation $Q_{in} = 0{,}003$ m at three different speeds of the diesel train. In this case, the curves Q_1, Q_2, Q_3 (Fig. 3, *a*) show the values of lateral deviation, and the curves φ_1, φ_2, φ_3 (Fig. 3, *b*) the angle of waggling of the wagon wheel pair at the speeds of the diesel train, such as 100 km/h, 120 km/h, 140 km/h, respectively.



a)



b)

Fig. 3. Graphs of lateral deviation and the angle of wagging of the wheeled pair of the wagon of rolling stock

It can be seen from the graphs in Figs 3, *a* and *b* that with increasing speed of the diesel train along sections of the railway track with irregularities, the frequency of the oscillations of the lateral ratio of the wheel pair of the railway wagon increases, as well as the rate of increase in the amplitude of the oscillations. In this case, fluctuations wagging of wheel pairs of the railway wagon have a similar character. Experiments on the models clearly explain the reasons for the appearance of strong transverse oscillations of railway wagons at speeds of the elements above 130 km/h.

In Fig. 4 shows the lateral deviation graphs (Fig. 4, *a*) and the wagging angle (Fig. 4, *b*) of the wheeled wagon of the rolling stock during the passage of the unevenness with the value of the initial displacement $Q_{in} = 0{,}003$ m at a speed $V \approx 120$ km/h for different values of the creep coefficient (K_1 = 10000 kN, K_2 = 15000 kN, K_3 = 20000 kN). It can be seen from the graphs in Fig. 4, *a* and Fig. 4, *b* that with an increase in the coefficient of creep the frequency of oscillation of the wheel pair of the railway wagon does not change, and the amplitude of the oscillations of the lateral ratio and the angle of wagering of the wheel pair decreases.

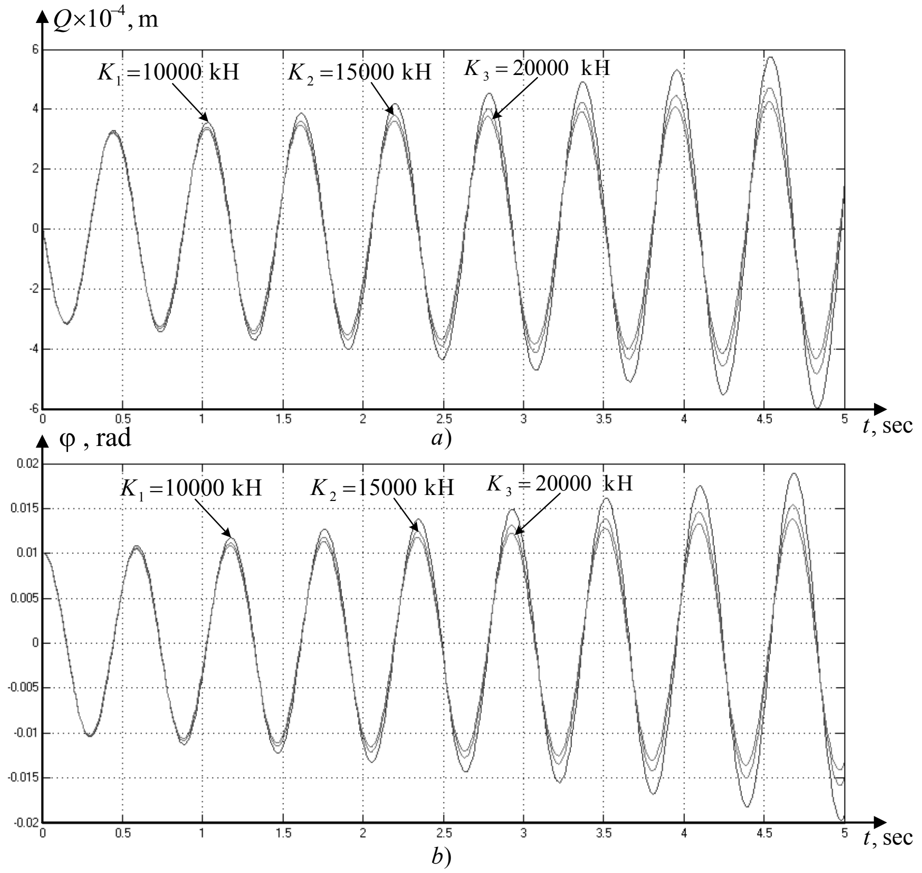


Fig. 4. Graphs of lateral deviation and the angle of wagging wheeled wagon rolling stock in the case of a change in the coefficient of creep

In Fig. 5 shows the lateral deviation graphs (Fig. 5, *a*) and the wagging angle (Fig. 5, *b*) of a wheeled wagon of a rolling stock in the process of passing an roughness with the value of the initial displacement $Q_{in} = 0{,}003$ m at speed $V \approx 120$ km/h for different values of the taper of a pair of wheels ($h_c = 0{,}02$; $h_c = 0{,}05$; $h_c = 0{,}08$). From the graphs in Fig. 5, *a* and Fig. 5, *b* can be seen that with increasing taper rolling surface, wheelset increases the frequency and amplitude of the oscillations and the lateral deflection of the wheelset yaw angle of diesel trains wagons.

In Fig. 6 shows the graphs of lateral deviation and the angle of wobble of the wheeled wagon during the acceleration of the diesel train to speed $V = 120$ km/h on an uneven section of the railway track with the next roughness: in a period of time $t = [0 – 20]$ sec – the initial value of offset $Q_{in} = 0{,}005$ m; in a period of time $t = [20 – 60]$ sec – the initial value of offset $Q_{in} = 0{,}003$ m; in a period of time $t = [60 – 100]$ sec – the initial value of offset $Q_{in} = -0{,}002$ m; in a period of time $t = [100 – 120]$ sec – the initial value of offset $Q_{in} = 0{,}001$ m.

From the graphs in Fig. 6 it becomes obvious that as the speed of the rolling stock increases during acceleration along the uneven part of the railway track, the frequency and amplitude of the longitudinal oscillations and the angle of wagging of the wheel pair of the diesel train wagon tends to increase, which leads to uncomfortable sensations (swaying) of the train passengers, even at the small speed of the rolling stock along the sections of the road with small irregularities. In this regard, it is necessary to take into account the lateral deviation and the angle of wagging of rolling stock wagons when synthesizing the optimal rules control the diesel train to ensure comfortable conditions for passengers during the movement of the train at high speeds.

In studies of diesel train work processes at speeds of up to 120 - 130 km/h, relations (12) and (13) it is advisable to exclude from the model.

In investigating of acceleration processes, movement rolling stock processes at constant speed, on coasting and braking can be used a system of equations (1) - (11).

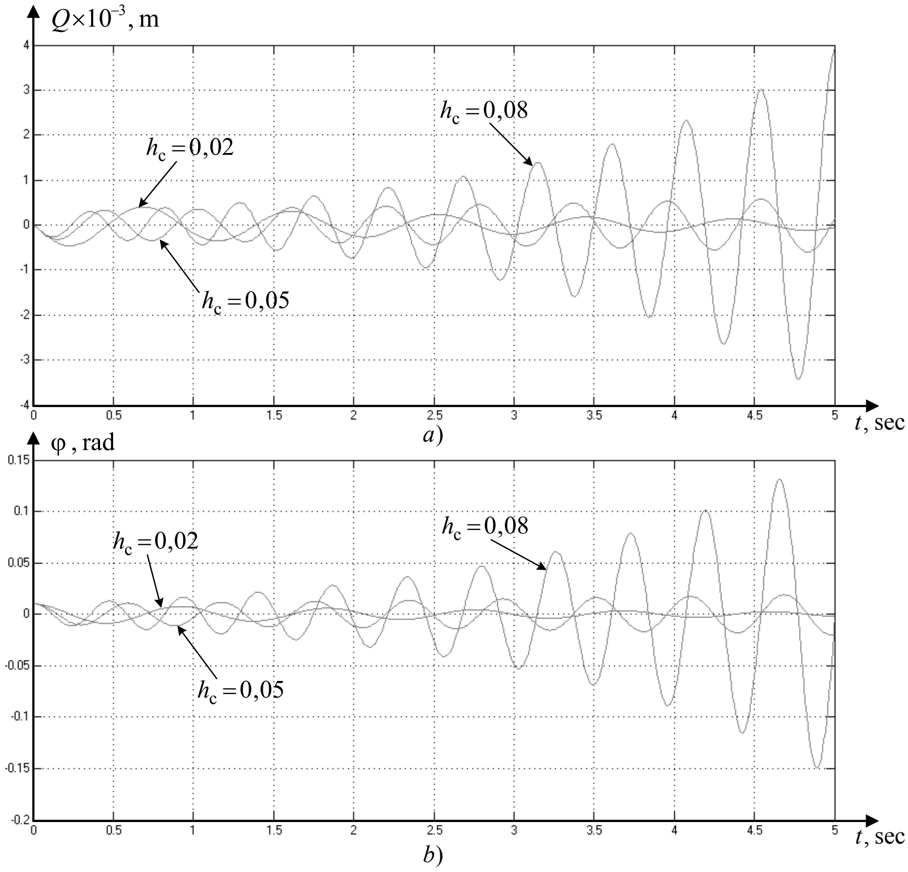


Fig. 5. Graphs of lateral deviation and the angle of waggling of the wheelset of the wagon of rolling stock for different values of taper

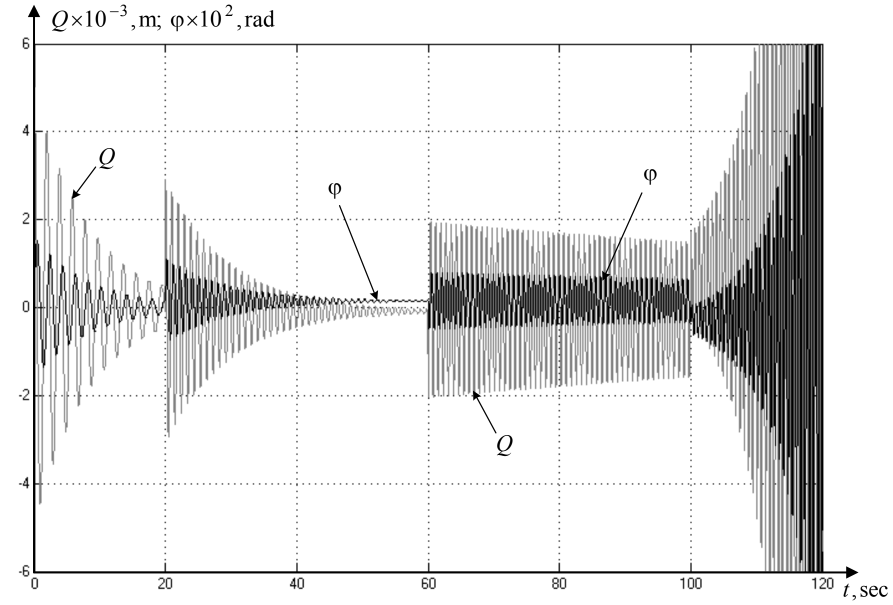


Fig. 6. Graphs of lateral deviation and wobble of the wheel pair of the diesel train wagon during its acceleration on an uneven section of the track

In Fig. 7 shows the graphs of the time changes of the first, second and third railway wagons of diesel train, obtained with the help of the developed complex mathematical model (1) - (13) (curves V_1, V_2, V_3), acceleration of the first train railway wagon (curve a), the traversed path (curve S_1), forces, acting between the first and second (curve F_{12}), and the second and third train railway wagons (curve F_{23}) as it moves between the two stations, as well as the position of the traction (curve N_{cm}) and the brake (curve N_{tcm}) controllers of the train machinist. Also, Fig. 7 shows the graphs of the processes, obtained with the use of one (first) railway wagon with drive of the diesel train, operating at 1 to 6 positions of the driver's traction controller (curve N_{tcm}). In addition, in Fig. 7 also shows graphs of the variation the speed of rain motion in time (curve V_t) and the path, traversed by the train from the start of the railway track section (curve S_2) obtained on the real object by means an onboard diesel train information-measurement system of DEL-02, during its movement over the smooth section of railway track $S = 3$ km during the time $t = 5$ min.

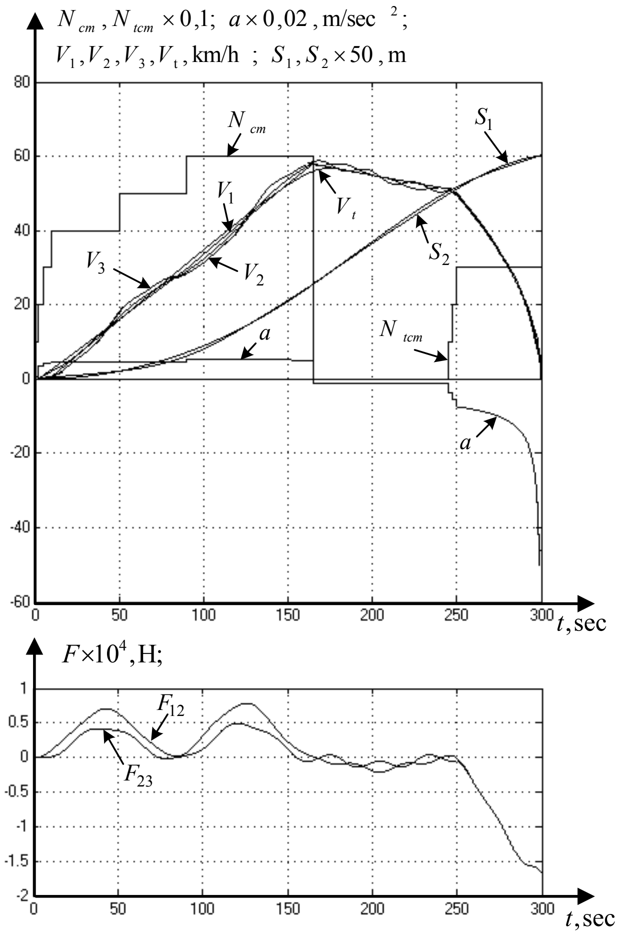


Fig. 7. Graphs of the main processes of motion, obtained on the complex mathematical model (1) - (11) and the real diesel train DEL-02

From Fig. 7 that the graphs of the speed and the path, traversed by the rolling stock, obtained with the help of the complex mathematical model (1) - (11) and on the real diesel train DEL-02, practically coincide. And also, the value of the forces acting between the first and second (Fig. 7, the curve F_{12}), and the second and third railway wagons of the train (Fig. 7, curve F_{23}) coincides with the same forces that are modeled in the works [7, 8]. All this testifies to the adequacy of the complex mathematical model (1) - (11) to the real object of control, which is a diesel train DEL-02.

In the case when the processes of skidding and longitudinal oscillations of wagons have already been studied, when only motion modeling operations of diesel train along a section of the railway track are needed, from model (1) - (13) it is necessary to exclude only the first six equations, with one equivalent electric motor.

A lot of experiments that were carried out on the complex mathematical model (1) - (13) and the real diesel train DEL-02, confirmed the adequacy of the model to the control object under consideration. In this regard, the model (1) - (13) can be used to study the dynamic processes of trains motion with traction asynchronous drives, check the optimal control rules for rolling stock.

INVESTIGATION OF THE DYNAMIC PROCESSES OF ROLLING STOCK MOTION ON A COMPLEX MATHEMATICAL MODEL

Consider using a complex mathematical model (1) - (13) example of mutual influence of longitudinal and transverse vibrations while driving railway wagons of diesel train on the route between two stations, the distance between which is $S = 3$ km, in a period of time $t = 5$min on an even section of the railway track, taking into account the unevenness of the railway track and the current limits on the maximum acceleration value $(-1 \div -0{,}7 \text{ m/sec}^2 \le a \le 0{,}7 \div 1 \text{ m/sec}^2)$, related to the comfort of traveling passengers in the modes of acceleration and braking.

In Fig. 8 shows the results of modeling, on a complex mathematical model (1) - (13), the motion of a diesel train on a flat section of a railway track with three irregularities on $t = 50$ sec, 150 sec and 250 sec with the value of the initial displacement of the railway wagon $Q_{in} = 0{,}03$ m.

In Fig. 8, as represented the graphics positions of the traction in time change (N_{cm}) and brake (N_{tcm}) controllers of the machinist, instantaneous speeds of the first, second and third railway wagons of the diesel train (V_1, V_2, V_3), the way that was passed (S), as well as energy (E), that consumes diesel train while moving between two stations. In Fig. 8, *b* shows the variation of the distance between the railway wagons of the train, and in this case the curves dS_{12} and dS_{23} show the change in the distance between the first and second, and second and third train wagons, respectively. In Fig. 8, *b* the presented graphs of the variation in time of forces acting between the first and second (curve F_{12}), and second and third railway wagons (curve F_{23}) when moving a diesel train between two stations along a section of the road with irregularities.

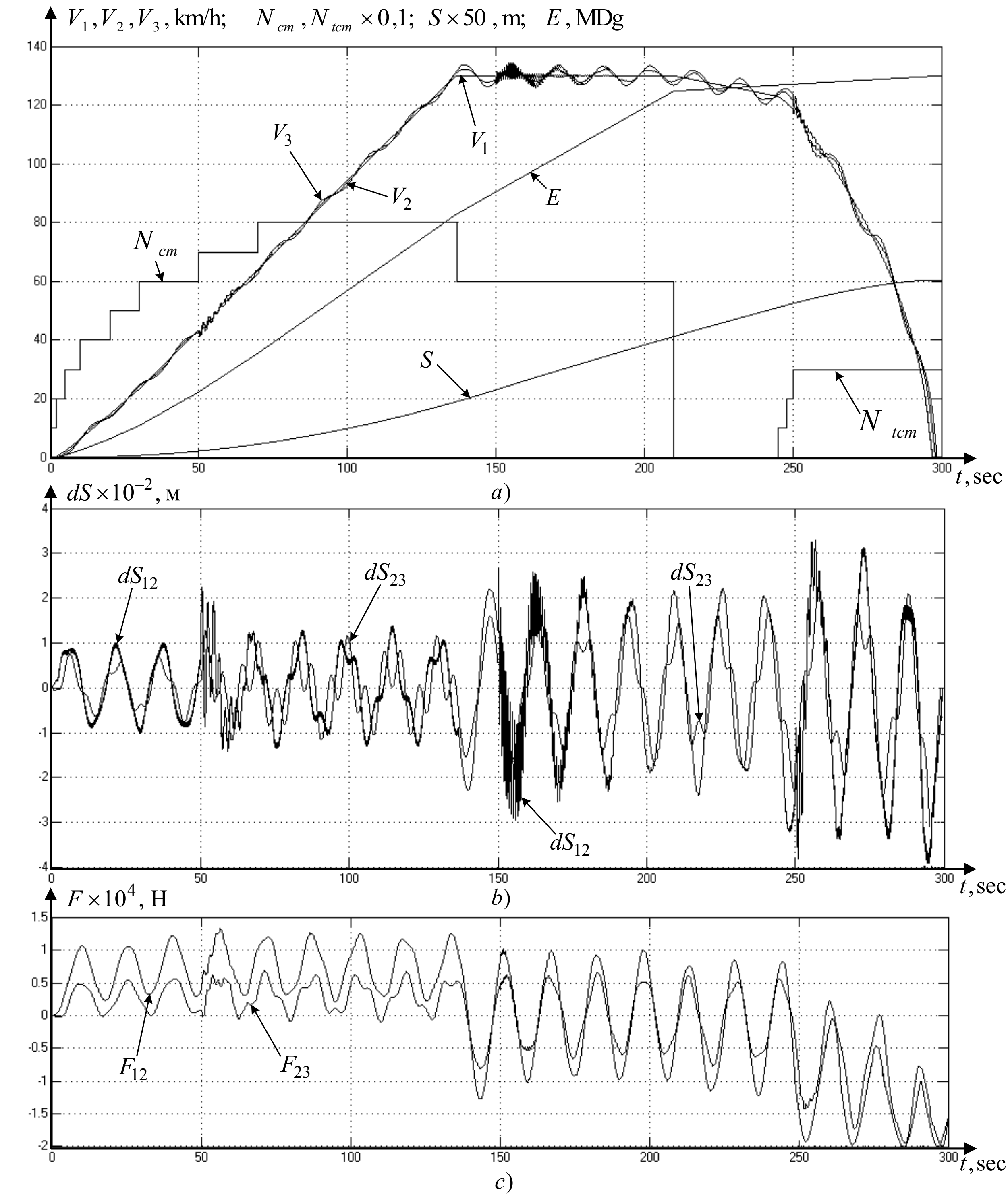


Fig. 8. Results of modeling the diesel train motion on a complex model (1) - (13)

In Fig. 9, curves Q and φ, show, respectively, the lateral deviation and the angle of wagging of the second railway wagon of the train when it passes through irregularities along the above-described section of railway path.

From the graphs in Fig. 8 it can be seen that during the passage of the diesel-train sections of the road with irregularities, the lateral deflection Q and the wobbling angle φ of the second train wagon, shown in Fig. 9, affects the longitudinal oscillations of all the railway wagons of the train, which leads to their jerking and changing the distance between the first and second, and also the second and third railway wagons of the train. In addition, lateral deviation and wagging of thesecond railway wagon affects the forces acting between the railway wagons, which manifests itself in the form of insignificant oscillations of forces acting between the first and second, and also the second and third railway wagons of the rolling stock (Fig. 9, time intervals [50, 75] sec, [150, 175] sec, and [250, 275] seconds).

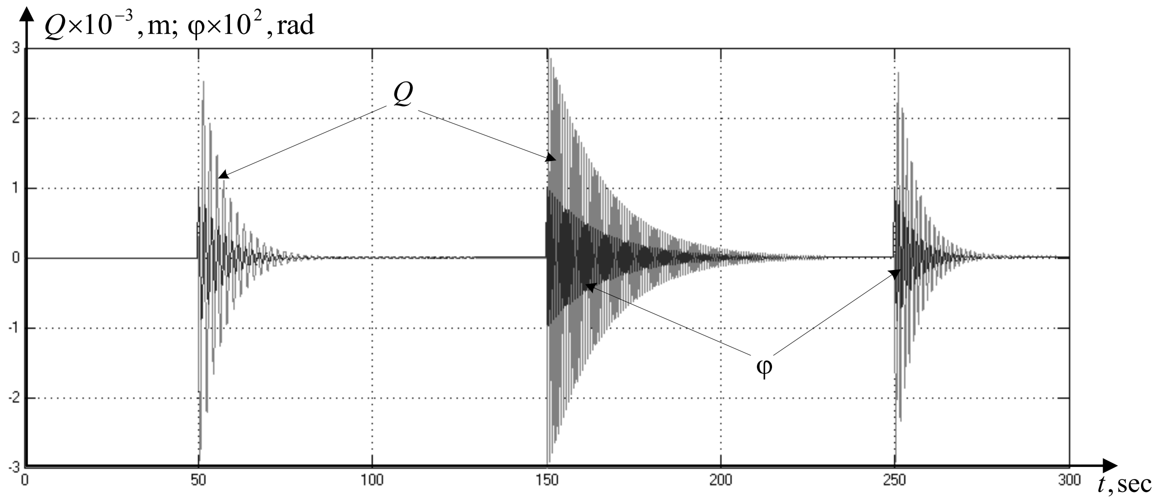


Fig. 9. Transverse vibrations and the angle of wagging of the second railway wagon when the diesel train is moving

CONCLUSIONS

The theory of traction rolling stock modeling has been further improved by developing a complex mathematical model for the motion of diesel trains, which is in contrast to existing models allows you to explore a wide range of dynamic operating modes: longitudinal oscillations of wagons, lateral deviations and angles of waggering of rolling stock cars, modes of acceleration, traction and braking of the train, taking into account skidding, as well as electromagnetic processes in electric motors, which made it possible to more accurately describe the processes, taking place in the control object.

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Research on the effect of surface resistance of vibrating sieve on the free-flowing mixture motion

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Summary. The paper is devoted to the study of the effect of changing the value of the resistance of the working surface on the nature of the mixture motion and its kinematic characteristics on the vibrating sieve. The regularities of the thickness of the layer, the longitudinal and transverse velocity components, the surface density of the dry mixture and the specific loading at the entire surface area of the vibrating sieve at different values of the resistance of the working surface have been determined. The value of the resistance of the sieve surface to the motion of a vibro-liquefied grain mixture is given by the phenomenological Chézy coefficient.

A mathematical model of the spatial motion of a dry mixture on vibrating sieves of a finite width [23] was used for the research. The system of equations of motion was reduced to the plane flow equations. The effect of sifting the mixture on the motion was not taken into account. The initial velocity at the sieve input has a convex profile in width and is approximated by the equation of parabola.

The increase of the resistance of the sieve causes the transition from accelerated motion of the mixture to uniform one, reducing the magnitude of the longitudinal and transverse velocity components and increasing the surface density of the mixture. The thickness of the layer does not vary across the area of the sieve and does not depend on the resistance. The nature of the dependences of longitudinal velocity and surface density is almost unchangeable with the length of the sieve at large values of resistance. In width of the sieve, the dependences have a convex profile, which gradually levels towards the outlet. The nature of the transverse component remains unchanged. Uneven distribution of the specific loading of the sieve gradually decreases towards the inlet with increasing value of the resistance of the working surface. The distribution pattern does not change and is conditioned by the profile of the longitudinal velocity.

Key words: vibrating sieve, mixture flow, specific loading, resistance of the sieve surface.

INTRODUCTION

The process of separating the free-flowing mixture begins with the motion on the vibrating sieve surface. The character of the motion and its kinematic parameters determine the efficiency of the separation process. The components of the separation process – segregation and sifting through the holes – depend on the longitudinal and transverse components of the speed of the mixture, the thickness and density of the layer, the specific loading of the working surface of the sieve.

One of the main factors determining the nature of the motion is the strength of the sieve surface resistance to the mixture stream. In the majority of works [1-3], the resisting strength is considered as the friction force, which is determined by the coefficient of friction on the metal surface. At the same time, the working surface of the sieve is not smooth, but, on the contrary, it's perforated. The holes have different shapes and sizes, which adds additional resistance to the motion of the stream. The edges of the holes of the sieves have micro burrs, formed as a result of mechanical stamping, which cut into grains and slow them down. The grains, stuck in the openings, tower above the surface of the sieve and, thus, provide an additional obstacle. To intensify the separation process aerators, mechanical rabbles, activators, gatherers of various design and other elements resisting motion are installed on the working surface of the sieve.

Thus, in many cases, the resisting strength value varies and, therefore, has a various effect on the kinematic characteristics of the flow. Thus, the study of the effect of surface resistance of vibrating sieve on the free-flowing mixture motion is a crucial task.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

In works [4, 5] the effect of the resistance of the working surface of the vibrating pneumatic centrifuge on the kinematic characteristics of the grain mixture was investigated. The working surface is made of air-permeable, with oblique asymmetric furrows, arranged in a chess order and directed with vertical edges towards the grain mixture motion. It was established that the density and velocity of the mixture layer on the developed surface are reduced, but their variation in length and width of the working surface is not investigated. The grain mixture motion is modeled by a material point method, which cases significant errors in the results of the study.

In the work [6], the Navier-Stokes equation is applied to study the motion of a vibro-liquefied grain mixture. The resistance of the mixture motion on the sieve was established to differ considerably from that on the the non-perforated surface. Edges and bridges of rectangular holes introduce additional resistance and reduce the flow rate. In order to overcome this resistance, it is necessary to increase the intensity of the kinematic mode. The mixture motion is considered only in the longitudinal plane and the average speed of the mixture on the sieve is determined.

The investigation of the influence of the resistance of the grain mixture on the sieve with holes of a more complex shape was carried out in the papers [7-11]. The holes in the shape of three- and five- petaled epicycloids and hypotrochoids have been developed and substantiated. A hydrodynamic model of a bubble pseudo-fluidized medium was created to determine the velocity distribution. It was determined that velocity components are periodic functions of spatial variables in the plane of a structural vibrating sieve, and their values depend on the mutual position and geometry of the sieve holes. However, the distribution of velocity components on the surface of vibrating sieve of finite width and length is not investigated in the work.

Dynamic loads on the sieve sheet due to the action of the cleaners and inertial ones due to the fluctuations of the sieve states cause various bends of the sheets, which are a source of additional perturbation of the grain mixture and change resistance to the motion. A mathematical model of the influence of a grain mixture, structural and kinematic parameters of separators and surface intensifiers on the spectrum of frequencies and forms of normal and constrained vibrations of the sieve sheet has been developed in the papers [12-15]. The interconnection between the coefficient of dry friction of particles and the hydrodynamic characteristics of the flow is obtained, numerical values of the bulk friction coefficients, dynamic and kinematic viscosity are determined. However, the distribution of velocities and the flow density, depending on the resistance of the mixture, created by the fluctuations of the sieve sheet, has not been investigated.

The study of the influence of the resistance of the grain mixture on the sieve, on the surfaces of which the aerators of the mixture in the shape of ribs and rifts are installed, were performed in the works [16, 17], bulk band-wave-like intensifiers – in works [14, 18], rectangular bulk activators – [7, 19, 20]. The theory of rapid motion of granular dry materials by Goodman-Savage-Cohen was applied for the modeling of the grain mixture motion [21, 22]. The dependences of the volume density, porosity, velocity of the grain mixture on the depth of the layer from the structural parameters of the aerators and the specific loads on the working surface are obtained. It is established that porosity and velocity decrease with depth and the nature of these dependencies is nonlinear. The use of aerators reduces bulk density and average flow velocity, but increases the velocity gradient over the depth of the layer. However, the works consider one-dimensional stationary motion of the mixture layer, in which the flow characteristics depend only on the depth of the layer and are taken equal to the width and length of the sieve.

In majority of the works, considerable attention was paid to determination of the value of the resistance forces, depending on the structural and kinematic parameters of the new designs of sieves and devices that intensify the separation process. The influence of the resistance of the working surface only on the individual characteristics of the flow of the mixture is investigated; in particular, the dependences of their variation on the entire sheet of the vibrating sieves are not available.

OBJECTIVE

The purpose of the work is to study the effect of changing the value of the resistance of the working surface on the nature of the mixture motion and its kinematic characteristics on the entire sheet of the vibrating sieves.

THE MAIN RESULTS OF THE RESEARCH

A mathematical model of the spatial motion of a dry mixture on vibrating sieves of a finite width [23] was used for the research. The system of equations of motion was reduced to the plane flow equations. The main precondition for such a transformation is the insignificant thickness of the layer compared with the linear dimensions in the plane of the flow, and the fact that the change in the velocity components along the normal to the sieve is very small. The effect of sifting the mixture on the motion was not taken into account.

The system of equations of the planned flow of a flake mixture on a vibrating sieve has the form [24]:

$$\frac{\partial}{\partial t}\gamma + u\frac{\partial}{\partial x}\gamma + \mathrm{v}\frac{\partial}{\partial y}\gamma + \gamma\frac{\partial}{\partial x}u + \gamma\frac{\partial}{\partial y}\mathrm{v} = 0, \tag{1}$$

$$\begin{gathered}\frac{\partial}{\partial t}u + u\frac{\partial}{\partial x}u + \mathrm{v}\frac{\partial}{\partial y}u + \frac{g\cos\theta}{2}\frac{\partial}{\partial x}h + \\ + \frac{hg\cos\theta}{2\gamma}\frac{\partial}{\partial x}\gamma - \frac{2\mu h}{\gamma}\frac{\partial^2}{\partial x^2}u - \frac{\mu h}{\gamma}\frac{\partial^2}{\partial y^2}u - \\ - \frac{2\mu}{\gamma}\frac{\partial}{\partial x}h\frac{\partial}{\partial x}u - \frac{\mu}{\gamma}\frac{\partial}{\partial y}h\frac{\partial}{\partial y}u - \\ - \frac{\mu}{\gamma}\frac{\partial}{\partial y}\left(h\frac{\partial}{\partial x}\mathrm{v}\right) + \frac{C_s}{\gamma}u - g\sin\theta = 0,\end{gathered} \tag{2}$$

$$\begin{gathered}\frac{\partial}{\partial t}\mathrm{v} + u\frac{\partial}{\partial x}\mathrm{v} + \mathrm{v}\frac{\partial}{\partial y}\mathrm{v} + \frac{g\cos\theta}{2}\frac{\partial}{\partial y}h + \\ + \frac{hg\cos\theta}{2\gamma}\frac{\partial}{\partial y}\gamma - \frac{\mu h}{\gamma}\frac{\partial^2}{\partial x^2}\mathrm{v} - \frac{2\mu h}{\gamma}\frac{\partial^2}{\partial y^2}\mathrm{v} - \\ - \frac{\mu}{\gamma}\frac{\partial}{\partial x}h\frac{\partial}{\partial x}\mathrm{v} - \frac{2\mu}{\gamma}\frac{\partial}{\partial y}h\frac{\partial}{\partial y}\mathrm{v} - \\ - \frac{\mu}{\gamma}\frac{\partial}{\partial x}\left(h\frac{\partial}{\partial y}u\right) + \frac{C_s}{\gamma}\mathrm{v} = 0,\end{gathered} \tag{3}$$

where x, y are the current coordinate values in the Cartesian system; u,v –projections of the particle velocity on the axis of the Cartesian coordinate system; γ – surface density of the mixture; g – acceleration of free fall; θ – the angle of inclination of the sieve; h – thickness of the layer, measured along the normal to the bottom of the tray to the free surface; t – time; μ – the dynamic coefficient of shear viscosity; C_s – a phenomenological coefficient similar to the Chézy coefficient.

The three equations (1-3) contain four unknown functions. To close this system of equations, the kinematic boundary condition on the free surface of the layer is adopted:

$$\frac{\partial h}{\partial t} + u\frac{\partial h}{\partial x} + \mathrm{v}\frac{\partial h}{\partial y} = 0. \tag{4}$$

As can be seen from the equations of the dynamics of a thin layer, the domain of unknown functions is $\sum_0=\{0<x<l,\ -l_1/2<y<l_1/2\}$. Here, l is the length of the sieve, l_1 – its width. The boundary of this area consists of the lines

$$L_1=\{0<x<l, y=-l_1/2\},$$
$$L_2=\{0<x<l, y=l_1/2\},$$
$$L_3=\{x=0, -l_1/2<y<l_1/2\},$$
$$L_4=\{x=l, -l_1/2<y<l_1/2\}.$$

The distributions are given at the boundary L_3:

$$h(t,0,y)=H^0(t,y),\quad \gamma(t,0,y)=G^0(t,y),$$
$$\mathrm{u}(t,0,y)=\mathrm{U}^0(t,y),\quad \mathrm{v}(t,0,y)=V^0(t,y). \tag{5}$$

The following conditions are fulfilled on the lines L_1, L_2:

$$\mathrm{v}(t,x,-l_1/2)=0,\quad \left.\frac{\partial u}{\partial y}\right|_{y=-l_1/2}-\left.\frac{C_s}{\mu}u\right|_{y=-l_1/2}=0, \tag{6}$$

$$\mathrm{v}(t,x,l_1/2)=0,\quad \left.\frac{\partial u}{\partial y}\right|_{y=l_1/2}+\left.\frac{C_s}{\mu}u\right|_{y=l_1/2}=0. \tag{7}$$

Numerical solution of equations is performed by finite-difference method [25 – 27].

Initial conditions:

$$h(0,x,y)=H^{(0)}(y)\exp(-\kappa x/l),$$
$$\gamma(0,x,y)=G^{(0)}(y)\exp(-\kappa x/l),$$
$$\mathrm{u}(0,x,y)=U^{(0)}(y)\exp(-\kappa x/l),$$
$$\mathrm{v}(0,x,y)=V^{(0)}(y)\exp(-\kappa x/l),$$

contain the parameter κ that determines the rate of decrease of the corresponding magnitude with the change of x (when $\kappa=0$, the initial data do not depend on x). In the future, we assume the values $H^{(0)}$, $G^{(0)}$, $U^{(0)}$ are stable, and $U^{(0)}$, we will associate with the second bulk flow Q by means of the ratio $Q=U^{(0)}l_1$. The value $V^{(0)}$ determines the velocity component transversely to the axis of the tray. Its value will be chosen in the form of functional dependence

$$V^{(0)}(y)=V_0^0\left[\frac{64}{3}\left(\frac{y}{l_1}\right)^3-\frac{16}{3}\frac{y}{l_1}\right].$$

At $V_0^0>0$ the flow tends to narrowing, and at $V_0^0<0$ – to expansion inside the tray.

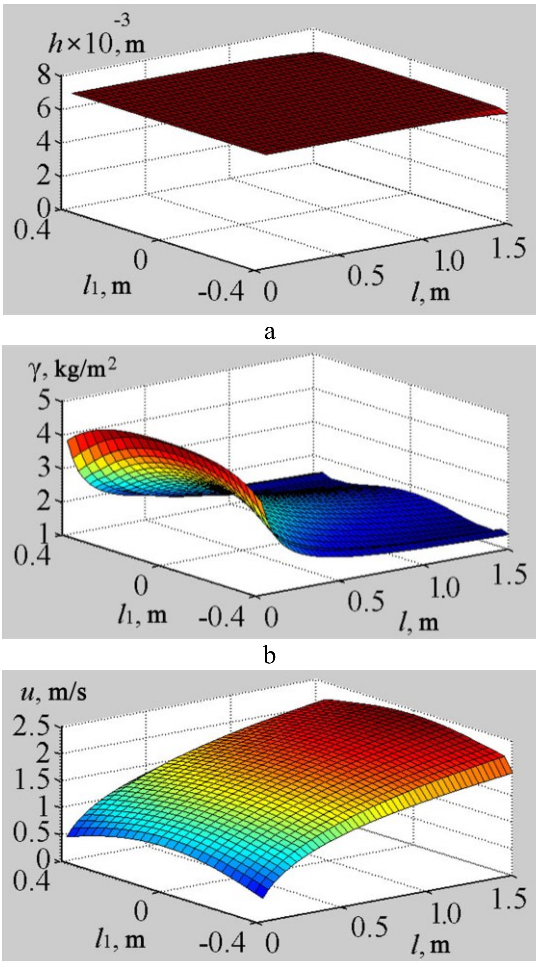
The specific loading of the sieve is $q=q(x,y)$

$$\mathrm{q}(x,y)=$$
$$=\lim_{\Delta x\to 0,\Delta y\to 0}\frac{1}{\Delta x\Delta y}\int_x^{x+\Delta x}\int_y^{y+\Delta y}\int_0^{h(x,y)}\rho(x',y',z)\times u(x',y',z)\,dz\,dx'\,dy'=$$
$$=\lim_{\Delta x\to 0,\Delta y\to 0}\frac{1}{\Delta x\Delta y}\int_x^{x+\Delta x}\int_y^{y+\Delta y}\gamma(x',y')u(x',y',z)\,dx'\,dy'=$$
$$=\gamma(x,y)\,\mathrm{u}(x,y).$$

Thus, $q(x,y)=\gamma(x,y)\,\mathrm{u}(x,y)$.

For numerical calculations we accept the following parameters of the process: the initial specific load is q=1200 kg/h·dm; the density of the dry mixture 800 kg/m^3; transverse to the axis of the sieve component of the speed of the mixture is V_0^0=0 m/s; the pressure on the surface of the mixture layer is P_0=20 kg/m·s^2; the length of the sieve is l=1.5 m; the width of the sieve is l_1=0.8 m; the angle of inclination of the sieve to the horizon is θ=10 deg; the empirical factor is κ=0; the coefficient of shear viscosity is μ=0.2 kg/m·s, the phenomenological coefficient, similar the Chézy coefficient is C_z=1-20 kg/m^2·s. The initial velocity at the sieve input has a convex profile in width and is approximated by the equation of parabola.

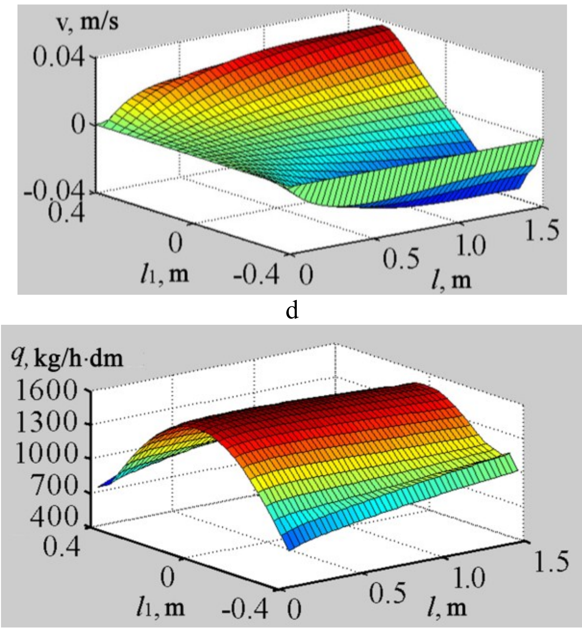
The distribution of the dry mixture flow characteristics on the vibrating sieve surface, for different values of the values of the resistance of the working surface, is presented in Fig. 1a-3a. The motion of the flow is characterized by the thickness of the layer, surface density, longitudinal and transverse component speed, specific loading of the working surface. The value of the resistance of the sieve surface to the motion of grain mixture is given by the phenomenological Chézy coefficient.



a

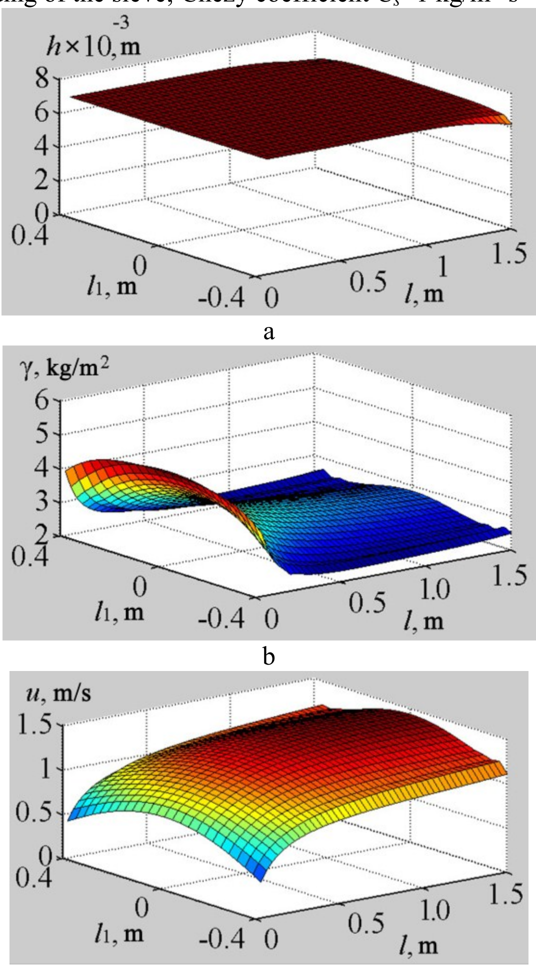
b

c

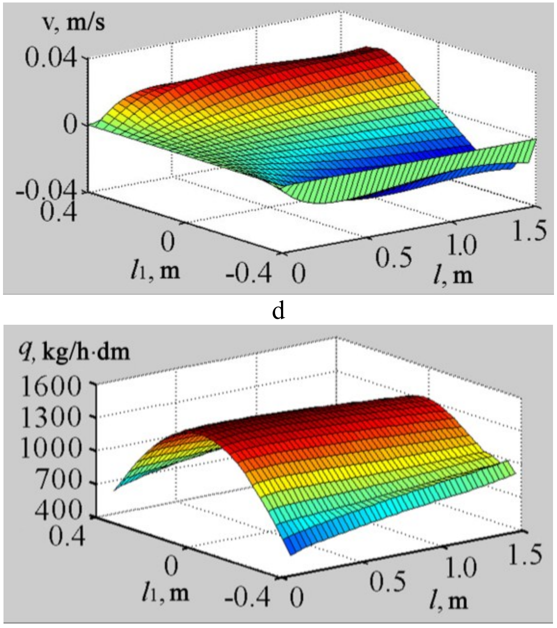


e

Fig.1. The characteristics of a dry mixture flow on a flat vibrating sieve: a) – the thickness of the layer; b) – the surface density of the mixture; c), d) – the longitudinal and transverse velocity components; e) – the specific loading of the sieve; Chézy coefficient C_s=1 kg/m^2·s

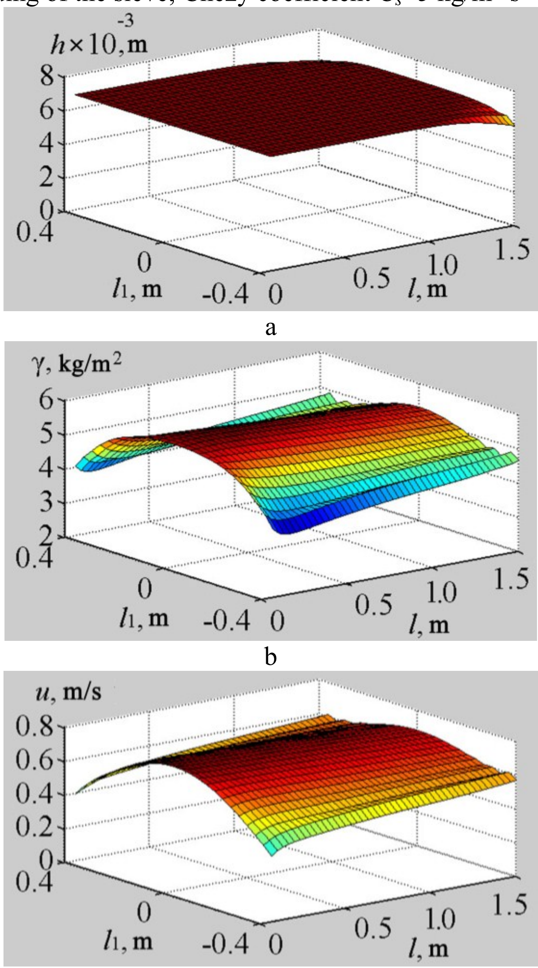


c

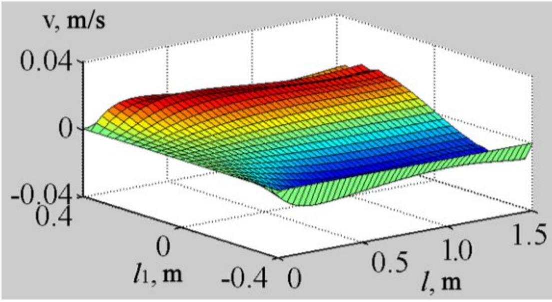


e

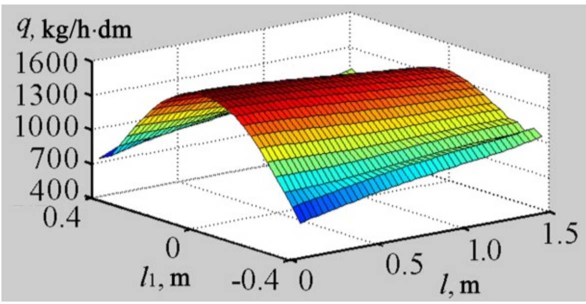
Fig.2. The characteristics of a dry mixture flow on a flat vibrating sieve: a) – the thickness of the layer; b) – the surface density of the mixture; c), d) – the longitudinal and transverse velocity components; e) – the specific loading of the sieve; Chézy coefficient C_s=5 kg/m^2·s



c



d



e

Fig.3. The characteristics of a dry mixture flow on a flat vibrating sieve: a) – the thickness of the layer; b) – the surface density of the mixture; c), d) – the longitudinal and transverse velocity components; e) – the specific loading of the sieve; Chézy coefficient C_s=20 kg/m^2·s

The thickness of the layer of a dry mixture remains almost unchanged throughout the sieve area, and its value does not depend on the resistance of the working surface (Fig. 1a -3a).

For small values of the resistance of the working surface, the Chézy coefficient is equal to C_s=1 kg/m^2·s, the surface density of the mixture decreases asymptotically with the length and has a convex profile along the width of the sieve (Fig. 1b). The longitudinal component of the dry mixture velocity increases along the length of the sieve, which indicates an accelerated motion (Fig. 1c). The velocity distribution across the width of the sieve has a convex profile, which is determined by the initial velocity profile at the sieve input. At the side walls a decrease in speed is observed. The transverse component of the mixture velocity (Fig. 1d) is very small in size compared with the longitudinal and directed to the lateral walls. The specific loading pattern is determined by the magnitudes of longitudinal velocity and surface density. They are the largest at the longitudinal axis of the sieve, so this area is overloaded, and the distribution of specific loading in width has a convex profile (Fig. 1e). In general, loading of the sieve is uneven across its area, and the largest deviations occur at the inlet of the flow.

With average values of the working surface resistance, the Chézy coefficient is equal to C_s=5 kg/m^2·s, the surface density of the mixture decreases at the beginning of the sieve, and then almost does not change with the length (Fig. 2b). The distribution of width density has a convex profile, which gradually levels towards the outlet of the flow, along with the density increasing. The longitudinal velocity component at the beginning of the sieve increases, and then stabilizes, which indicates a transition to a uniform motion (Fig. 2c). The values of the longitudinal and transverse components of the velocity decreased (Fig. 2c, d). Since the reduction of the mixture velocity occurs with simultaneous increase in density, the nature of the specific loading does not change with the increase in resistance, but at the outlet the uneven character of the distribution decreases (Fig. 2e).

At high values of the resistance of the working surface, the Chézy coefficient is equal to C_s=20 kg/m^2·s, the surface density increased considerably, retains a convex profile and almost does not change its length (Fig. 3b). The longitudinal velocity component decreased in size significantly, it does not vary with length, but its profile in width tends to level gradually towards the outlet of the flow (Fig. 3c). The transverse component of the velocity also decreased in value, but the character of its distribution did not change (Fig. 3 d). The nature of the distribution of the specific loading in the width did not change and is conditioned by the convex profile of the longitudinal velocity (Fig. 3 e). However, the magnitude of the deviations of the overloaded central and underloaded lateral sections decreased towards the inlet which indicates a decrease in the uneven character of the distribution of the loading.

CONCLUSION

1. The increase of the resistance of the sieve causes the transition from accelerated motion of the mixture to uniform one, reducing the magnitude of the longitudinal and transverse velocity components and increasing the surface density of the mixture. The thickness of the layer does not vary across the area of the sieve and does not depend on the resistance.
2. The nature of the dependences of longitudinal velocity and surface density is almost unchangeable with the length of the sieve at large values of resistance. In width of the sieve, the dependences have a convex profile, which gradually levels towards the outlet. The nature of the transverse component remains unchanged.
3. Uneven distribution of the specific loading of the sieve gradually decreases towards the inlet with increasing value of the resistance of the working surface. The distribution pattern does not change and is conditioned by the profile of the longitudinal velocity.

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Results of experimental researches of tractor fluctuations KhTZ-242K.20

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Summary. The results of experimental research of oscillations of the tractors of the tractor KhTZ-242K.20 obtained using the measuring system of dynamics and energy of mobile machines are presented in the work. The spectral densities of vibro accelerations of tractor frames in three-dimensional space are calculated, depending on the velocity and traction resistance. The tractor has a hinged-connected arrangement, and the rear half-carriages of the tractor loaded with a ballast weighing 1500 kg. Fluctuations of the tractor's frame were obtained from experimental studies of traction dynamics of a tractor.

Key words: experimental research, tractor, spectral densities, fluctuations.

INTRODUCTION

Modern trends in the use of machine-tractor aggregates (MTA) in leading Ukrainian farms are aimed at increasing their seizing width and increasing the speed regime. However, when the MTA performs fieldwork, there are fluctuations in its component parts, in particular the engine, transmission and tractor frame. These vibrations of the tractor are caused by the unevenness of the resistance of the MTA movement, impacts and blows from the inequality of the surface of the soil and the fluctuations in the tractor's transmission (Galych I., Antoshchenkov R. 2017).

Fluctuations in the tractor cause over-pressurization of the soil, which complicates germination of plants and leads to a decrease in soil fertility (Zolotarevskaya D. 2013). In addition, these fluctuations lead to a breach of agrotechnical requirements, the creation of unfavorable conditions for growing plants (disturbed depths on the cultivation of soil, seeding, etc.), reduce the traction and coupling properties of the tractor, degrade the driver's working conditions, reduce the his labor-ability, have a detrimental effect on the work of mechanisms, causing their premature wear.

ANALYSIS OF RESEARCHES AND PUBLICATIONS

The reason for the oscillation is the kinematic inconsistency of the wheels and the support surface due to the change in the dynamic wheel radius, the rolling of the wheels, as well as the variations in the resistance of the tool and the tractor's rolling resistance, the engine's torque and transmission, and the continued vibrations of the tractor.

Significant role in the development of measures to reduce the oscillations of tractors should play methods to improve the indicators of smoothness of movement of tractors. Studies on the smoothness of cars, tractors and other vehicles were done by Anilovich B. Ya., Afanasyev V. L., Dmitriev A. A., Ka-Raban V. N., Melnikov A. A., Popov D. A., Yatsenko N. N. et al.

In the study of the smoothness of the course of MTA, the main source of oscillation of the frame, there is a micro-roughness of the field profile, which is of a random nature. Therefore, the smoothness of the movement of vehicles is considered on the basis of probability theory, spectral and correlation analysis of random processes. Most often, the maximum values of accelerations of the characteristic point of the sprung mass, the root-mean-square values of the accelerations, the type of amplitude-frequency characteristic of the system or the transfer function from field effects to point are used as criteria for smoothness of movement. (Gerasimenko V., Moskalenko T., Dolya A., Gritsuk I. 2009; Barsky I., Anilovich V., Kut'kov G. 1973).

When designing and testing new equipment, manufacturers try to satisfy all the needs of the customer and are therefore interested in the most in-depth research of products.

THE PURPOSE OF THE RESEARCH

The purpose of the article is analysis of the results of experimental research of the tractor tractor hinges KhTZ-242K.20.

THE RESULTS OF RESEARCH

When conducting experimental studies of traction dynamics of the KHTZ-242K.20 (Fig. 1) tractor, which took place at the experimental field of the Petro Vasilenko Kharkiv National Technical University of Agriculture (Merefa) (Shapovalov, Yu. et al. 2018), a study was conducted of the oscillations of the tractor half frame in three axes.

Fig.1. The object of experimental research is a tractor KhTZ-242K.20

For research was used the measuring system of the dynamics and energy of mobile machines developed by Antoshchenkov R.V. (Antoshchenkov R., & Antoshchenkov V. 2014). The measuring system relates to the technical means of diagnosis and operational control and can be used in agriculture and engineering industry. The system is designed to determine the kinematic, dynamic, power and energy characteristics of mobile machines and their elements during road, field and bench tests. The block diagram of the measuring system is shown in Fig. 2.

When testing, the tractor was equipped with an inertial measuring device (IMU-1) 6 which was installed on the first half of the tractor; inertial measuring device (IMU-2) 7 which was installed on the second half of the tractor; sensors wheel dynamics 8, located in the center of their rotation; electronic dynamometer 9. Communication between sensors, inertial measuring devices and computing module takes place via CAN bus 5. Power measurement system was carried out by gel lead-acid battery AGM. The data of research results are stored on the information carrier in the computing module 1, controlled by the remote control 2. A GPS navigation receiver 3 is connected to the module. The location of the sensors on the tractors is shown in Fig. 3.

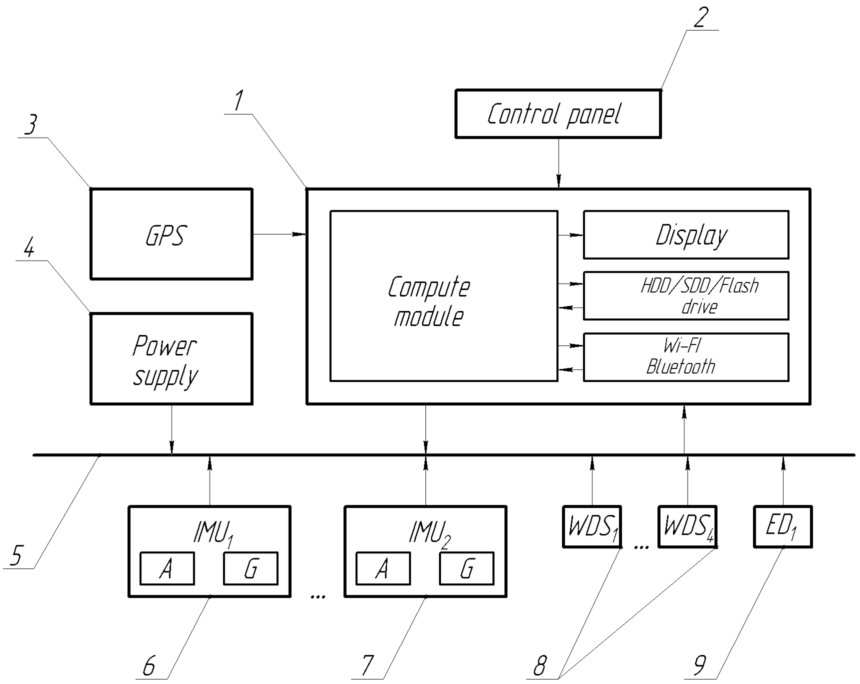

Fig. 2. Block diagram of the measuring system
1 – compute module; 2 – control panel; 3 – navigation receiver GPS; 4 – power supply unit; 5 – CAN data bus; 6, 7 – inertial measuring unit 1 and 2; 8 – gauges of the dynamics of the wheels (1…4); 9 – electronic dynamometer

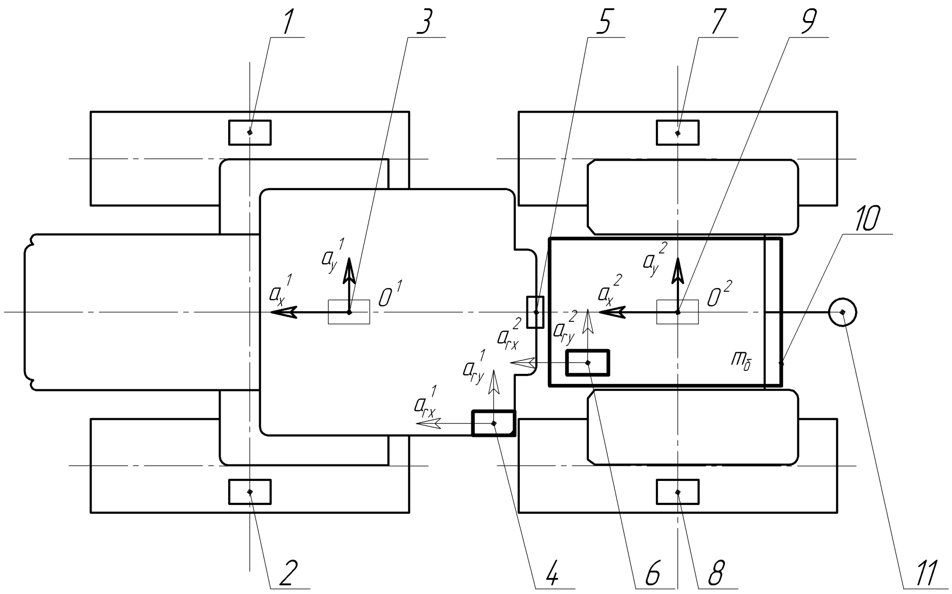

Fig. 3. Scheme of location of sensors on the tractor
1, 2, 7, 8 – gauges of the dynamics of the wheels (front left, front right, rear left, rear right); 3 – the center of mass of the first half of the tractor; 4 – inertial measuring unit (IMU-1); 5 – – navigation receiver GPS; 6 – inertial measuring unit (IMU-2); 9 – the center of mass of the second half of the tractor; 10 – ballast; 11 – traction force sensor

On the axes of rotation of the wheels dynamics sensors 1, 2, 7, 8 were installed. The oscillation of the first frame of the tractor was determined by IMU-1 4 corresponding to the second half of IMU-2 6. These sensors cannot be located in the centers of mass of the half-frames of the tractor 3 and 9, therefore the methodology used to compensate for the error of the sensors is used (Antoshchenkov R. 2017). The actual accelerations in the centers of the masses of the tractor's half-frames are determined. The antenna of the navigation receiver 5 is located on the tractor cabin symmetrically to the longitudinal axis.

The tractor is equipped with 10 ballast weighing 1500 kg, which is located on the second half of the tractor. The traction force was measured by an electronic dynamometer 11.

In comparative studies of the dynamics of mobile machines and their analysis, one of the characteristics of a stationary random process is the spectral density. In many cases, especially in the study of stationary random processes, the spectral density is a more convenient characteristic, in contrast to the correlation function (Olsson G., Piani D. 2001; Dyadyk V., Baidali S., Krynitsyn N. 2011; Lurie A. 1969). Such a technique is substantiated and used in the works (Primak I. 2002, Nadtiko V., Bodnova M. 2003). Therefore, to compare the dynamic indicators of the functioning of the elements of the aggregates, such as acceleration, trajectories of motion and other parameters, we use the spectral density determined by (Bendat J., Piersol A. 2013; Howard R.. 2004):

$$S_x(\omega) = \int_{-\infty}^{\infty} R_x(\tau) e^{-j\omega\tau} d\tau \tag{1}$$

where $x(t)$ – random stationary process; $R_x(\tau)$ – correlation function of random process.

The proposed algorithm is written using R-code for computation in GNU Octave or MATLAB:

```
% y – an array of input data;
L = length(y);
NFFT = 2^nextpow2(L);
Y = fft(y,NFFT)/L;
f = Fs/2*linspace(0,1,NFFT/2+1);
% Plot single-sided amplitude spectrum.
plot(f, 2*abs(Y(1:NFFT/2+1)), 'b');
```

The results of experimental studies in the form of spectral densities of vibration accelerations on the tractor's halves are shown in Fig. 4-9. The data for the vibration accelerations of the three-axle semicolons is obtained for the tractive effort on the tractor's hook. – $P_1 = 0$ kN, $P_2 = 40$ kN та $P_3 = 35$ kN; speed of movement – $\upsilon_1 = 1.45$ m/s, $\upsilon_2 = 2.3$ m/s, $\upsilon_3 = 4.08$ m/s.

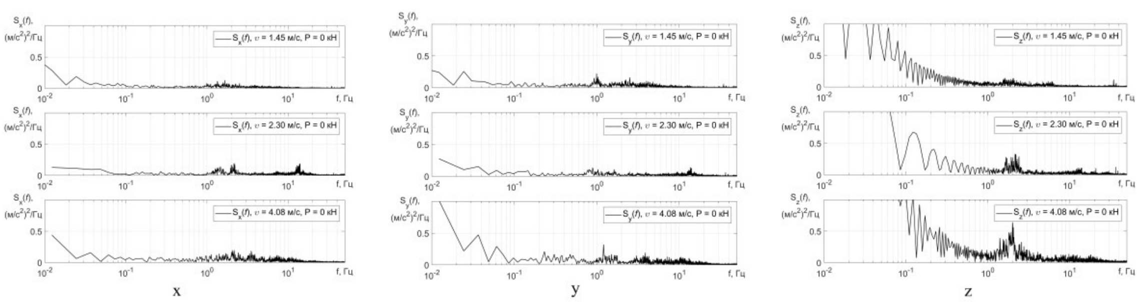

Fig.4. Spectral densities of vibration accelerations of the first half of the tractor (axis) P = 0 kN for speeds $\upsilon_1 = 1.45$ m/s, $\upsilon_2 = 2.3$ m/s, $\upsilon_3 = 4.08$ m/s

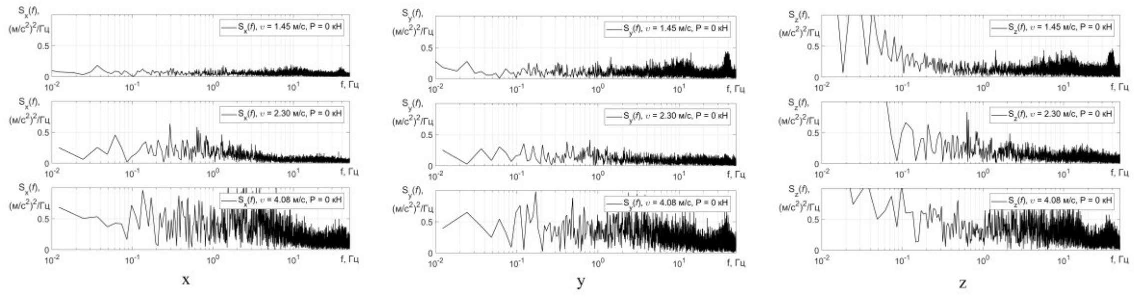

Fig.5. Spectral densities of vibration accelerations of the second half of the tractor (axis) P = 0 kN for speeds $\upsilon_1 = 1.45$ m/s, $\upsilon_2 = 2.3$ m/s, $\upsilon_3 = 4.08$ m/s

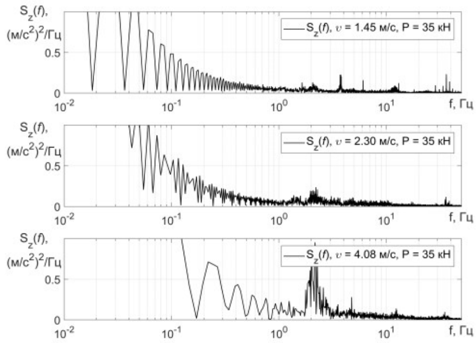

Fig. 6. Spectral densities of vibration accelerations of the first half of the tractor (z axis): P = 35 kN for speeds υ_1 = 1.45 m/s, υ_2 = 2.3 m/s, υ_3 = 4.08 m/s

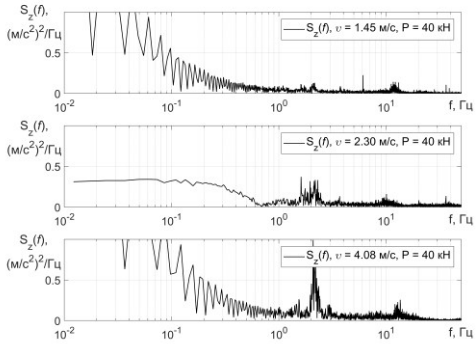

Fig. 7. Spectral densities of vibration accelerations of the first half of the tractor (z axis): P = 40 kN for speeds υ_1 = 1.45 m/s, υ_2 = 2.3 m/s, υ_3 = 4.08 m/s

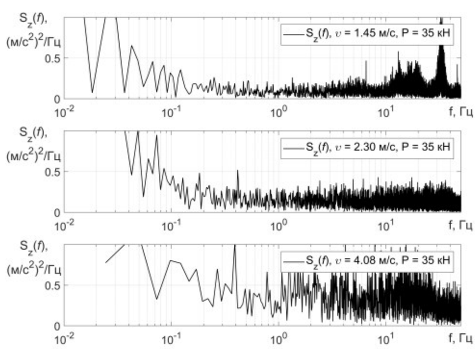

Fig. 8. Spectral densities of vibration accelerations of the second half of the tractor (z axis): P = 35 kN for speeds υ_1 = 1.45 m/s, υ_2 = 2.3 m/s, υ_3 = 4.08 m/s

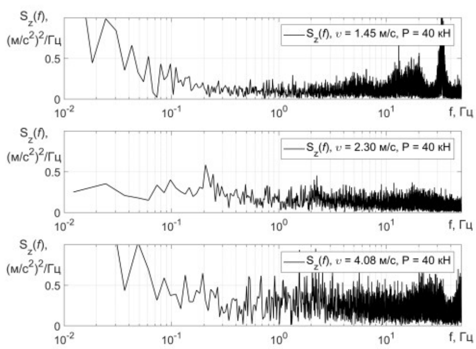

Fig. 9. Spectral densities of vibration accelerations of the second half of the tractor (z axis): P = 40 kN for speeds υ_1 = 1.45 m/s, υ_2 = 2.3 m/s, υ_3 = 4.08 m/s

Spectral densities of the vibration accelerations of the first half of the tractor along the x and y axes for traction forces from 0 to 40 kH and the velocities from υ_1 = 1.45 m/s to υ_3 = 4.08 m/s do not exceed 0.5 $(m/s^2)^2$/Hz. On the z axis, the spectral density of the acceleration vibrations of the first half of the tractor increases to 1.0 $(m/^{s2})^2$/Hz at a frequency of 2.1 Hz, and also Sz (f) = 0.25 $(m/s^2)^2$/ Hz at f = 11 Hz.

The oscillations of the second half of the tractor have a large energy in the wider spectrum. The axes x, y, and z show an increase in the spectral density to 1.1 $(m/s^2)^2$/Hz for all modes of operation of the tractor. The spectral density of the vibration accelerations along the z-axis has a significant increase to 1.1 $(m/s^2)^2$/Hz at a frequency of 41 Hz and a velocity 1.45 m/s.

CONCLUSIONS

1. The tractor's fluctuations have a negative effect, causing re-compaction of the soil, violation of agrotechnical requirements for cultivating crops, reducing the traction-coupling properties of the tractor, deteriorating driver's working conditions, etc.

2. Experimental studies of fluctuations in the semi-frame of the tractor KhTZ-242K.20, which has a hinged-linking arrangement, have been carried out. During research, the rear half-frame of the tractor was loaded with a ballast weighing 1500 kg. Using the measuring system of dynamics and energy of mobile machines, experimental data were obtained and the spectral densities of the vibration acceleration amplitudes for the tractor's halves in three-dimensional space were calculated, depending on the speed of the traction and the support.

3. Spectral densities of the vibration accelerations of the first half of the tractor along the x and y axes for traction forces from 0 to 40 kN and the velocities from υ_1 = 1.45 m/s to υ_3 = 4.08 m/s do not exceed 0.5 $(m/s^2)^2$/Hz. On the z axis, the spectral density of the acceleration vibrations of the first frame of the tractor increases to 1.0 $(m/s^2)^2$/Hz at a frequency of 2.1 Hz, and also Sz (f) = 0.25 $(m/s^2)^2$/Hz at f = 11 Hz. The fluctuations of the second half of the tractor have a large energy in the wider spectrum (Fig. 8-10). The axes x, y, and z show an increase in the spectral density to 1.1 $(m/s^2)^2$/Hz for all modes of operation of the tractor. The spectral density of the vibration accelerations along the z-axis has a significant increase to 1.1 $(m/s^2)^2$/Hz at a frequency of 41 Hz and a velocity υ_1 = 1.45 m/s.

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Cogeneration in agriculture

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Summary. In agriculture power and heat are very important. Cogeneration means producing power and heat at the same time, with higher efficiency and compactness, and lower emissions levels than conventional heating and power generation alternatives. Agriculture has the potential of producing renewable fuels and energy such as biogas, biodiesel, biomass, solar energy, etc. In this study, the application of cogeneration systems in agriculture is analyzed. Micro cogeneration systems and the technical and logistical problems associated with other cogeneration systems are also investigated. It is found that the energy efficiency and the exergy efficiency can reach about 90 % and 50 %, respectively.

Key words: cogeneration, power and heat, agriculture.

INTRODUCTION

In agriculture power and heat are very important. Cogeneration means producing power and heat at the same time, with higher efficiency and compactness, and lower emissions levels than conventional heating and power generation alternatives. Agriculture has the potential of producing renewable fuels and energy such as biogas, biodiesel, biomass, solar energy, etc. Typical energy crops for biogas production can include: Maize, Grass, Wheat, Rye, and Triticale. Alternatively other organic materials such as waste products may be used including: Slurry, Manure, Vegetable waste, agricultural/forest residues and Glycerol from biodiesel manufacture [1, 2].

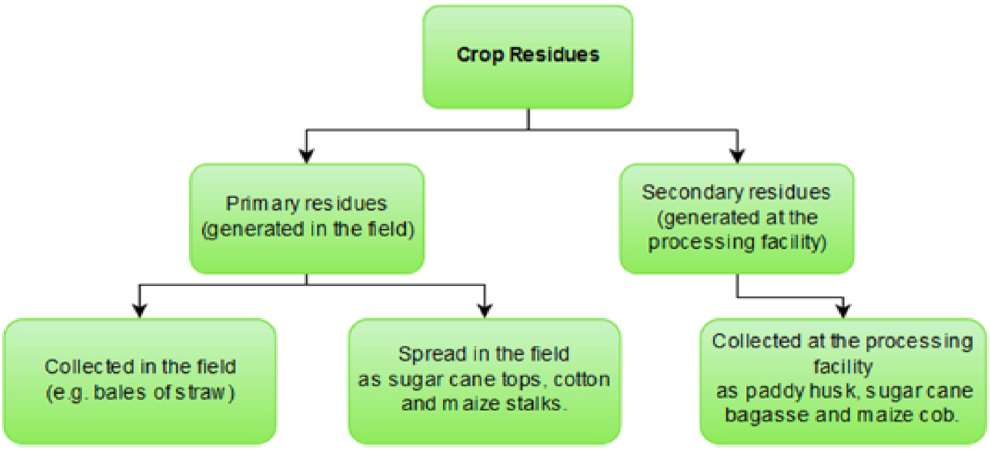

Fig. 1. Crop residue classification [2]

Agricultural biogas plants utilize organic materials found on farms. Organic materials are renewable fuel source. To produce energy crops the plant may be designed for it. These crops are typically ensilaged and stored in hoppers or clamps. They are continuously fed into the digester throughout the year [3, 4].

Biomethane producing is the best way to use in the micro-cogeneration systems. Bio methane is almost the same of methane of natural gas. There is three generation or methods to produce bio methane. The first-generation producing is by **decomposition** of the anaerobic decomposition of organic waste. The organic waste is the result of the natural breakdown of organic matter. This slightly pre-treated gas is biogas, and can be used locally to produce electricity or heat. By purification of the biogas becomes bio-methane, 100% renewable energy that can be used in vehicles.

The **second-generation bio-methane** is produced by **gasification** of ligno-cellulosic biomass (straw and wood), using a thermo-chemical conversion process. At first the biomass is converted into synthetic gas and then transformed into bio-methane by catalytic synthesis. The third generation bio-methane comes from the direct transformation of micro-algae. Micro-algae is cultivated in high-yield photosynthetic reactors using water, minerals and natural light, while recycling CO_2. This is an emerging technology [3].

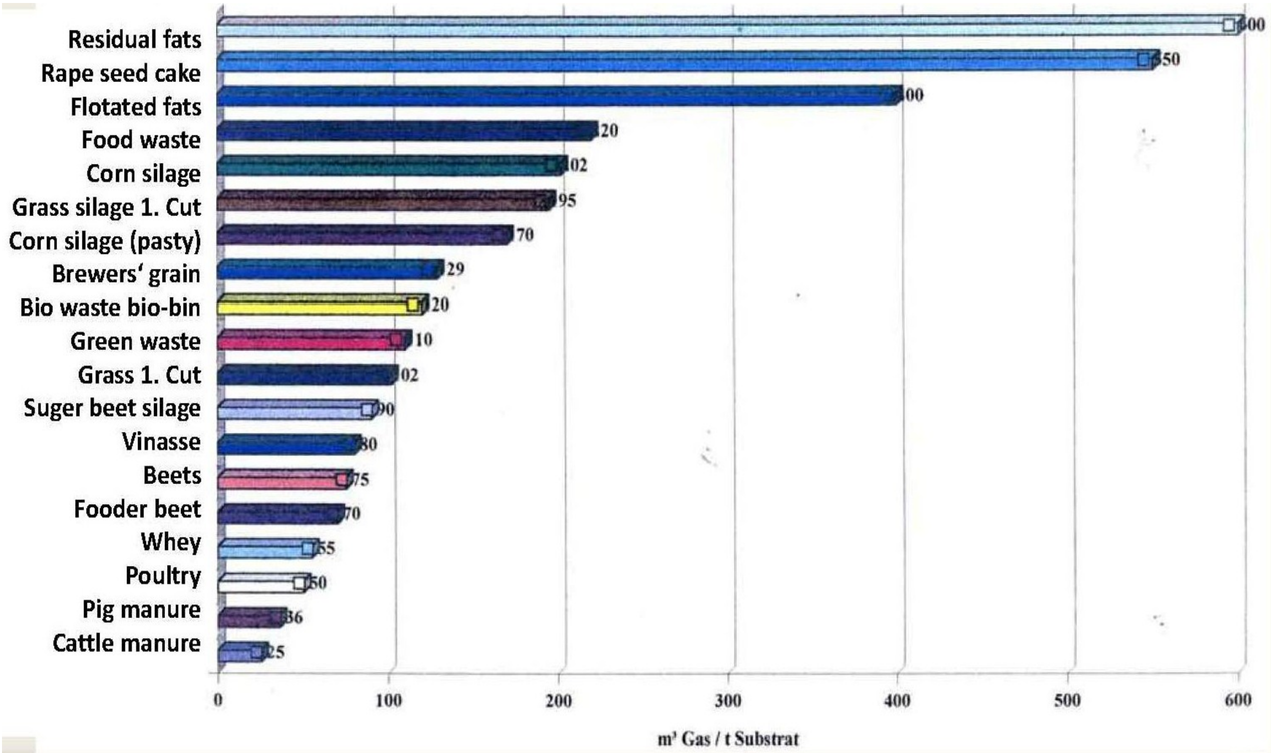

Fig. 2. Bio-methane potential from organic residuals [4]

Cogeneration systems are available for large or micro-scale industrial and commercial applications for decades. Cogeneration systems can also meet the energy demands of the agriculture industry. Providing reliable power and heat in remote lands that have no access to the natural gas or electric grid cogeneration systems are a good solution. Cogeneration systems produce heat and electricity with higher efficiency and lower emissions levels than conventional heating and power generation [5, 6, 7, 8]. Potential agricultural applications for cogeneration systems include horticulture, crop processing, water heating, dairy and animal farming, and space heating. Cogeneration through bagasse is a renewable strategy to meet the future energy needs. Electricity also can be produced from bagasse by installing special steam turbines and high pressure boilers. From 1000 kg of bagasse normally about 0.450 MWh of electricity is generated. By using conventional technology 3 kg of bagasse is required for generating 1 kWh of electricity. Conventional boilers can produce 2.2 t of steam at 23 bars with temperature 350 ^{0}C from one ton of baggase, 11 kg steam is consumed to generate 1kWh of electricity [9, 10].

THE RESULTS OF RESEARCH

The schematic diagram of the air-fuel preheated (recuperated) cycle is given in Figure 3. In the) cycle the compressed air and fuel are heated by hot the exhaust gases in two different recuperators. After that the hot air and the heated fuel enters the combustion chamber for combustion. After the combustion in the chamber, the hot gases are expanded at the gas turbine to obtain work and from the gas turbine. The hot gases exit the turbine and become the source of the heat recovery steam generator and air fuel heating [11, 12]. The cycle is fueled with bio-methane. The assumptions are taken in modeling of the cycle are, the environmental conditions are taken as T_0 = 298.15 K and P_0 = 1.013 bar the pressure losses in the combustion chamber, air preheater and HRSG are known as 5 %, the main capacity of the air compressors are m_1 = 91.4 kg/s, HRSG m_s = 14 kg/s saturated steam at 20 bar, the gas turbine net electric power is 30 MW (net electric power is equal to the mechanic power obtained from the gas turbine minus mechanic power used by compressor), and the combustion chamber's inlet fuel is m_f = 1.64 kg/s methane. Methane LHV is taken as 802361.0 kJ/kMol [13, 14].

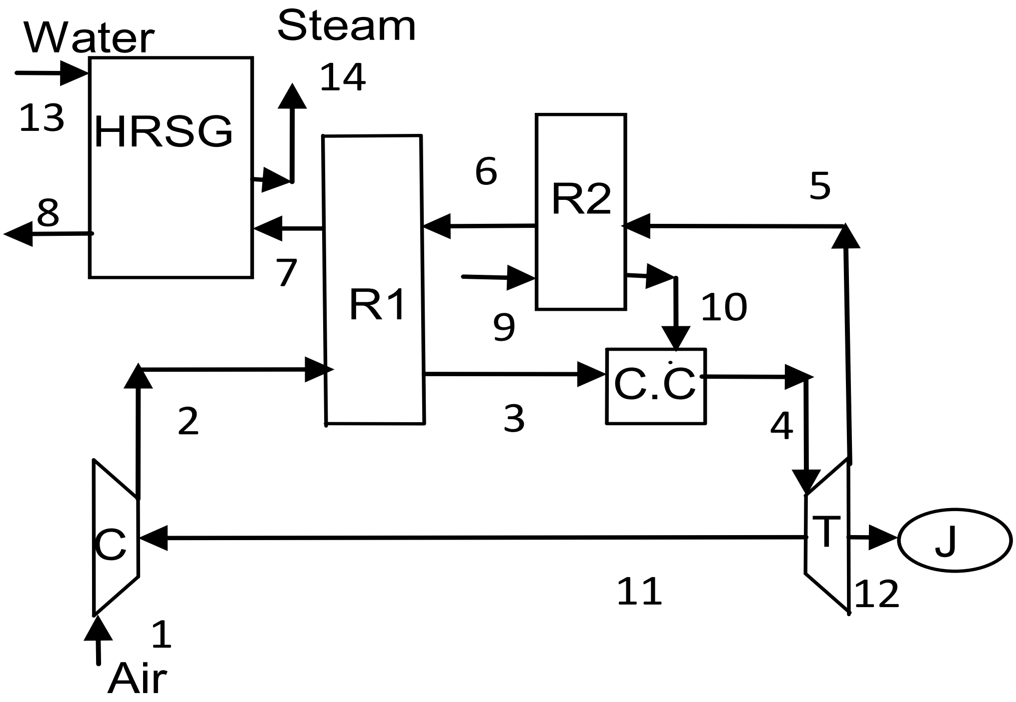

Fig. 3. Air fuel preheated (recuperated) cogeneration cycle

Table 1. The mass, the energy and the entropy equations of the components of the air fuel preheated cycle [13, 14].

Component	Mass Equation	Energy Equation	Entropy Equation
Compressor	$\dot{m}_1 = \dot{m}_2$	$\dot{m}_1 h_1 + \dot{W}_C = \dot{m}_2 h_2$	$\dot{m}_1 s_1 - \dot{m}_1 s_2 + \dot{S}_{gen,C} = 0$
Recuperator1	$\dot{m}_2 = \dot{m}_3$ $\dot{m}_6 = \dot{m}_7$	$\dot{m}_2 h_2 + \dot{m}_6 h_6 = \dot{m}_3 h_3 + \dot{m}_7 h_7$	$\dot{m}_2 s_2 + \dot{m}_6 s_6 - \dot{m}_3 s_3 - \dot{m}_7 s_7 + \dot{S}_{gen,R1} = 0$
Recuperator2	$\dot{m}_5 = \dot{m}_6$ $\dot{m}_9 = \dot{m}_{10}$	$\dot{m}_5 h_5 + \dot{m}_9 h_9 = \dot{m}_6 h_6 + \dot{m}_{10} h_{10}$	$\dot{m}_5 s_5 + \dot{m}_9 s_9 - \dot{m}_6 s_6 - \dot{m}_{10} s_{10} + \dot{S}_{gen,R2} = 0$
Combustion Chamber	$\dot{m}_3 + \dot{m}_{10} = \dot{m}_4$	$\dot{m}_3 h_3 + \dot{m}_{10} h_{10} = \dot{m}_4 h_4 + 0.02\dot{m}_{10} LHV$	$\dot{m}_3 s_3 + \dot{m}_{10} s_{10} - \dot{m}_4 s_4 + \dot{S}_{gen,CC} = 0$
Turbine	$\dot{m}_4 = \dot{m}_5$	$\dot{m}_4 h_4 = \dot{W}_T + \dot{W}_C + \dot{m}_5 h_5$	$\dot{m}_4 s_4 - \dot{m}_5 s_5 + \dot{S}_{gen,T} = 0$
HRSG	$\dot{m}_7 = \dot{m}_8$ $\dot{m}_{13} = \dot{m}_{14}$	$\dot{m}_7 h_7 + \dot{m}_{13} h_{13} = \dot{m}_8 h_8 + \dot{m}_{14} h_{14}$	$\dot{m}_7 s_7 + \dot{m}_{13} s_{13} - \dot{m}_8 s_8 - \dot{m}_{14} s_{14} + \dot{S}_{gen,HRSG} = 0$
Overall Cycle	$\bar{h}_i = f(T_i)$ $\bar{s}_i = f(T_i, P_i)$ $\dot{m}_{air} h_{air} + \dot{m}_{fuel} LHV_{CH4} - \dot{Q}_{Loss,CC} - \dot{m}_{eg.,out} h_{eg.,out} - \dot{W}_T - \dot{m}_{steam}\left(h_{water,in} - h_{steam,out}\right) = 0$ $\dot{Q}_{Loss,CC} = 0.02\dot{m}_{fuel} LHV_{CH4}$		

The mass, the energy and the entropy equations of the components of the air fuel preheated cycle are given at Table 1. The heat loss of the cycle is taken as $0.02.LHV.m_{fuel}$.

The exergy and the exergy efficiency equations of the components of the air fuel preheated cycle are given at Table 2. Chemical and physical exergy are taken into consideration.

Table 2. The exergy and the exergy efficiency equations of the components of the air fuel preheated cycle [13, 14].

Component	Exergy Equation	Exergy Efficiency
Compressor	$\dot{E}_{D,C} = \dot{E}_1 + \dot{W}_C - \dot{E}_2$	$\eta_{ex,C} = \frac{\dot{E}_{out,C} - \dot{E}_{in,C}}{\dot{W}_C}$
Recuperator1	$\dot{E}_{D,R1} = \dot{E}_2 + \dot{E}_6 - \dot{E}_3 - \dot{E}_7$	$\eta_{ex,R1} = \frac{\dot{E}_{out,air,R1} - \dot{E}_{in,air,R1}}{\dot{E}_{out,exhaust,R1} - \dot{E}_{in,exhaust,R1}}$
Recuperator2	$\dot{E}_{D,R2} = \dot{E}_5 + \dot{E}_9 - \dot{E}_6 - \dot{E}_{10}$	$\eta_{ex,R2} = \frac{\dot{E}_{out,air,R2} - \dot{E}_{in,air,R2}}{\dot{E}_{out,exhaust,R2} - \dot{E}_{in,exhaust,R2}}$
Combustion Chamber	$\dot{E}_{D,CC} = \dot{E}_3 + \dot{E}_{10} - \dot{E}_4$	$\eta_{ex,CC} = \frac{\dot{E}_{out,CC}}{\dot{E}_{in,CC} + \dot{E}_{fuel}}$
Turbine	$\dot{E}_{D,T} = \dot{E}_4 - \dot{E}_5 - \dot{W}_C - \dot{W}_T$	$\eta_{ex,T} = \frac{\dot{W}_{net,T} + \dot{W}_C}{\dot{E}_{in,T} - \dot{E}_{out,T}}$
HRSG	$\dot{E}_{D,HRSG} = \dot{E}_7 - \dot{E}_8 + \dot{E}_{13} - \dot{E}_{14}$	$\eta_{ex,HRSG} = \frac{\dot{E}_{steam,HRSG} - \dot{E}_{water,HRSG}}{\dot{E}_{in,exhaust,HRSG} - \dot{E}_{out,exhaust,HRSG}}$
Overall Cycle	$\dot{E} = \dot{E}_{ph} + \dot{E}_{ch}$ $\dot{E}_{ph} = \dot{m}(h - h_0 - T_0(s - s_0))$ $\dot{E}_{ch} = \frac{\dot{m}}{M}\left\{\sum x_k \bar{e}_k^{ch} + \bar{R}T_0 \sum x_k \ln x_k\right\}$ $\eta_{ex} = \frac{\dot{W}_{net,T} + (\dot{E}_{steam,HRSG} - \dot{E}_{water,HRSG})}{\dot{E}_{fuel}}$	

In Figure 4 variation of electric and heat energy rate with excess air rates for different pressure ratio are given. Recuperated cycle by preheating air and fuel uses some of the exhaust energy that decreases the energy of the heat recovery steam generator and that decreases the heat power. Increasing pressure ratio increases electric to heat energy rate of the cycle. The recuperators exit temperature is taken as 850 K. As can be seen that by increasing the compression rate, the electric power increases about 25 %, but the heat power decreases about 15 %.

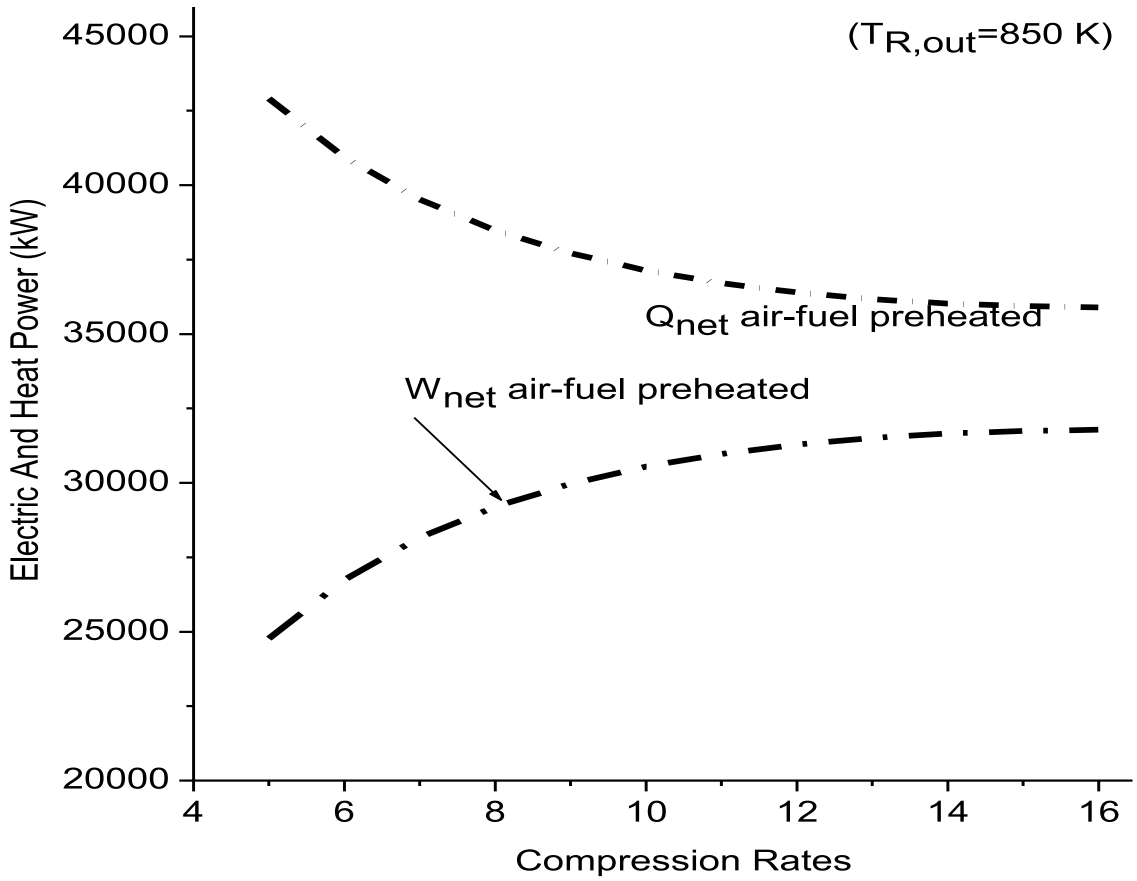

Fig. 4. Variation of electric and heat power with pressure ratio for the cycle.

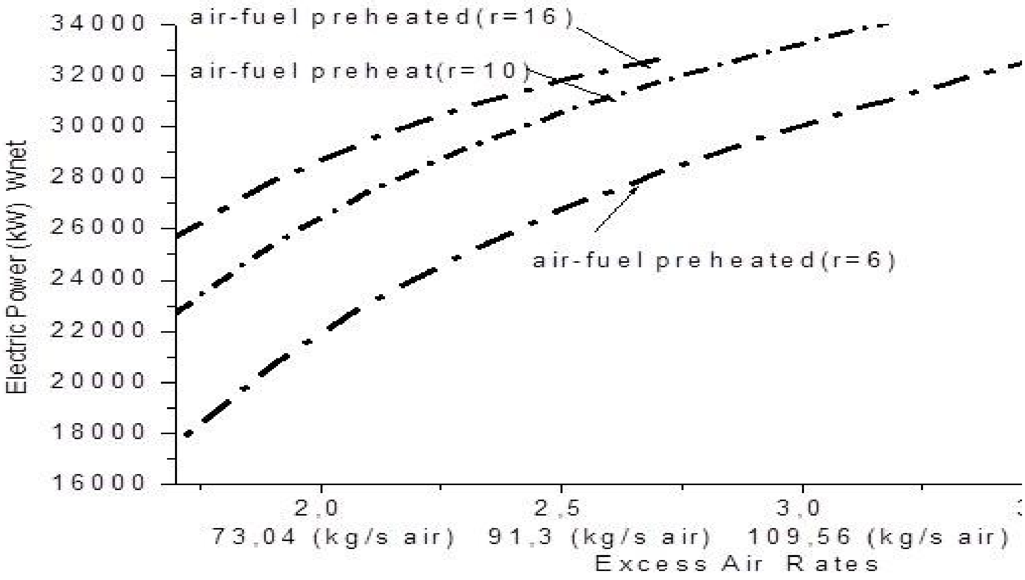

Fig 5. Variation of electric power with excess air rates for different pressure ratio.

In Figure 5 variation of electric power with excess air rates for different pressure ratio are given. Increasing excess air rates increases the electric power of the cycle. Also increasing pressure ratio increases the electric power of the cycle. Increasing the compression ratio of the cycle increases the electrical power, but decreases the heat energy. Increasing the compression ratio increases the combustion chamber outlet temperature which increases the turbine work, but decreases the amount of heat obtained from HRSG. Electric power of air-fuel preheated cycle increases about 35 % by excess air rate range 1.3 to 3.5 at compression rate 10.

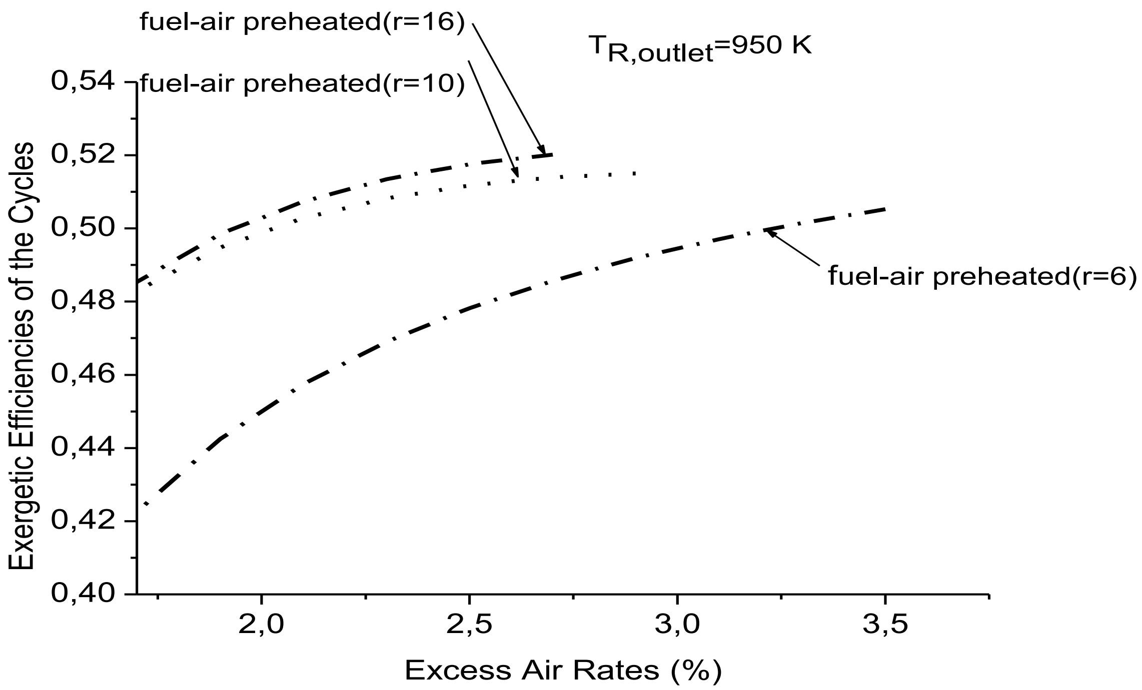

Fig 6. Variation of exergetic efficiency with excess air rates for different pressure ratio.

Variation of exergetic efficiency with excess air rates for different pressure ratio is given in Figure 6. Increasing compression ratio increases the exergetic efficiency of the cycle. The reason for this is that; increasing compression ratio increases the outlet temperature of the combustion chambers which means that increasing the inlet temperature of the turbine increases the exergetic efficiency. For the pressure ratio of 6 increasing excess air rate from 1.5 to 3.5 increases the exergetic efficiency from %42 to %50. The increases for the pressure ratio of 10 and 16 the exergetic efficiency, increases less than the pressure ratio of 6. As a conclusion it is found that the energy efficiency and the exergy efficiency can reach about 90 % and 50 %, respectively.

By using crop residue, Bio-methane producing is the best way to use in the micro-cogeneration systems in agricultural heat and power generation for demand. Increasing the compression ratio of the cycle increases the electrical power, but decreases the heat energy. Increasing the compression ratio increases the combustion chamber outlet temperature which increases the turbine work, but decreases the amount of heat obtained from HRSG. Electric power of air-fuel preheated cycle increases about 35 % by excess air rate range 1.3 to 3.5 at compression rate 10. Increasing compression ratio increases the exergetic efficiency of the cycle. As a conclusion it is found that the energy efficiency and the exergy efficiency can reach about 90 % and 50 %, respectively.

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A research on cogeneration systems in energy systems

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Summary. Energy is such important factor of our lives. Cogeneration systems are one of the most efficient forms of energy source. Cogeneration systems are generally used in factories to generate electricity and thermal energy from an energy source. The fact that the factories themselves use their own electricity supply systems is a major contributor to the country's economy. Cogeneration means that electricity and heat energy are produced together. These systems have two different applications, gas turbine and gas engine. Cogeneration systems are more efficient than traditional systems (systems where electricity and heat energy are generated separately). The efficiency of cogeneration systems is around 80-90%. Therefore, the use of Cogeneration Systems provides great advantages.

Key words: Cogeneration, turbine, gas engine, yield.

INTRODUCTION

The cogeneration is made up of the abbreviation of "Combined Generation“ terms. It means "combined production" in which heat and electricity are produced together. They are more efficient than single-purpose production systems because they extract more energy available from the same fuel source. The first simple examples of cogeneration systems were seen in the first half of the 20th century. But it was abandoned during the cheap fuel period. 1973- 1979 was developed and reapplied after the oil crises. [1]

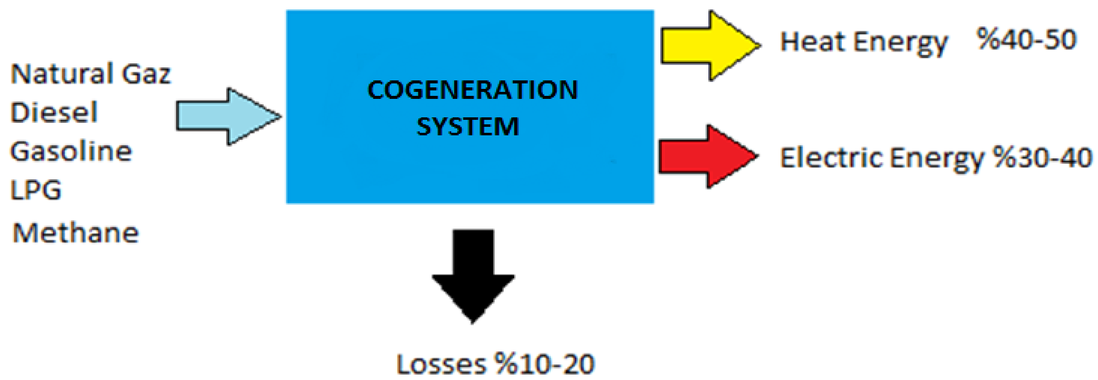

Fig. 1. Cogeneration System

A Cogeneration System (CHP=Combined Heat And Power) consists of four basic elements.

- Turbine or engine
- Electric generator
- Heat recovery system (in case of cooling, an absorption cool unit)
- Control system

It can only convert about 30-40% of the energy used by a gas turbine or gas engine that produces electricity. If this system is used in the form of cogeneration, a large part of the heat energy to be discharged from the system can be converted to usable energy so that the total energy input can be evaluated between 70-90%.[2]

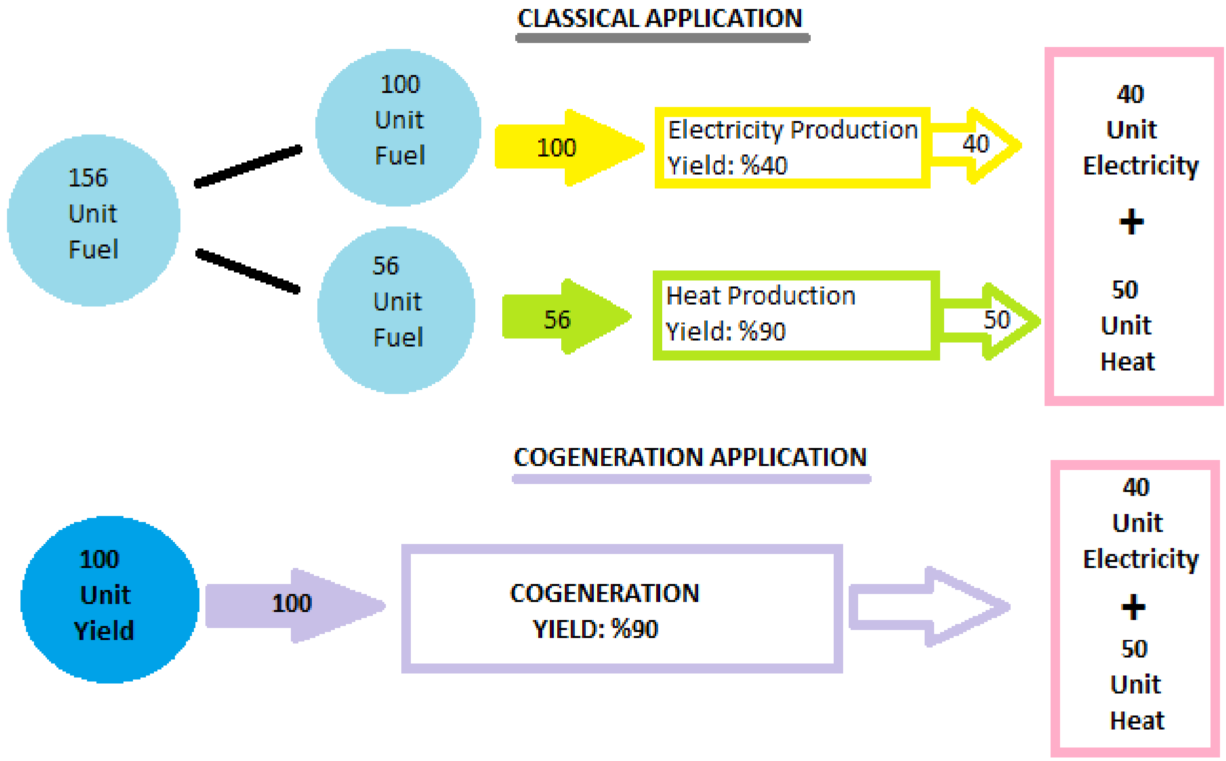

Fig. 2. The Difference Of Cogeneration Systems Forom Classical Aplications

Today, projects where cogeneration is most applied are projects where continuous thermal energy requirement is needed and electricity consumption is high. Shortly, these are; Factories, Hotels and Amusement Centers, The Places where localized heating is used (for instance, workplaces, houses), Hospitals and troops, Universities and Goverments builds, Waste water treatment facility, Industry / Commercial Affair areas, The places where gardening is done and airports

- ✓ Saving local or imported energy resources.
- ✓ Thanks to cogeneration systems which are built in plants, electrical energy transmission and distribution losses decrease
- ✓ Cogeneration systems have low heat emmision to nature according to other electricity production systems.
- ✓ Total Energy Cost Of the company reduces, so it increases the competitive power of the company
- ✓ The operator will have the guarantee of energy supply, and the losses caused by production discontinuities will be abolished.[3]

High-efficiency primary energy use efficiency will save local or imported energy resources. The reason for the energy plant (cycle) to be realized at the consumption site and electrical transmission and distribution connection and system losses and transmission losses will be minimized. Expensive investment, transmission and distribution facility investments will not be needed. It is possible to build and operate in smaller and local companies as it is built in small power and size. The production of energy in the places of consumption will be healthier in terms of national security. In general, the national energy cost will be reduced in large quantities. There will be no electricity interruptions, frequency and voltage irregularities that may be at the highest level in quality and continuity in the produced energy. In the long run the system will finance itself. Solid, liquid and gaseous effects that may occur per unit of production capacity of the plant will e less than a central power plant that generates electricity only, or an industry that produces only steam. Because of the exhaust gases used for waste heat application, CO emissions are very low. Such a system is also advantageous in terms of environmental pollution, which will be one of the most controversial topics on the world in the coming periods. It causes less load on national electricity generation and distribution. The cash and similar losses that may arise from the production interruptions of the operator are minimized. Getting more energy by spending less fuel increases country revenues. As these systems develop and spread, new investments create new business fields. [4]

Cogeneration is implemented through two types of main drive units.These are shown in figure 3.

Fig. 3. Gas Turbine-Gas Engine or Diesel Engine

Gas turbines are widely used in the 4.5-20 MW power range for cogeneration applications. On the other hand, Gas engines are being applied at smaller forces. However, it is not right to limit gas motor cogeneration applications to this dimension. Up to 100 MW to 3 MW are available in a single module, and 10 MW levels can be achieved in multi-module power plants.

In gas turbines, exhaust gas heat can be used to produce steam, hot water or hot oil according to the process needs. In gas engines, about 1/3 of the waste heat is recovered from the exhaust gas and 2/3 from the cooling systems. The cooling circuits consist of cylinder-jacket cooling, oil cooling in the crankcase and turbocharger cooling, in which the heat from the exhaust heat exchanger is added.

The kinetic energy generated by burning the mixture of fuel and air (12-35 bar) in the combustion chamber drives the generator via turbine and gearbox. Thus, electric energy is obtained from the generator. Exhaust emissions of gas turbine systems are around 400-500 ° C. Saturated steam and / or hot water can be obtained from the turbine outlet through a direct heat exchanger (waste heat boiler) under the conditions required.

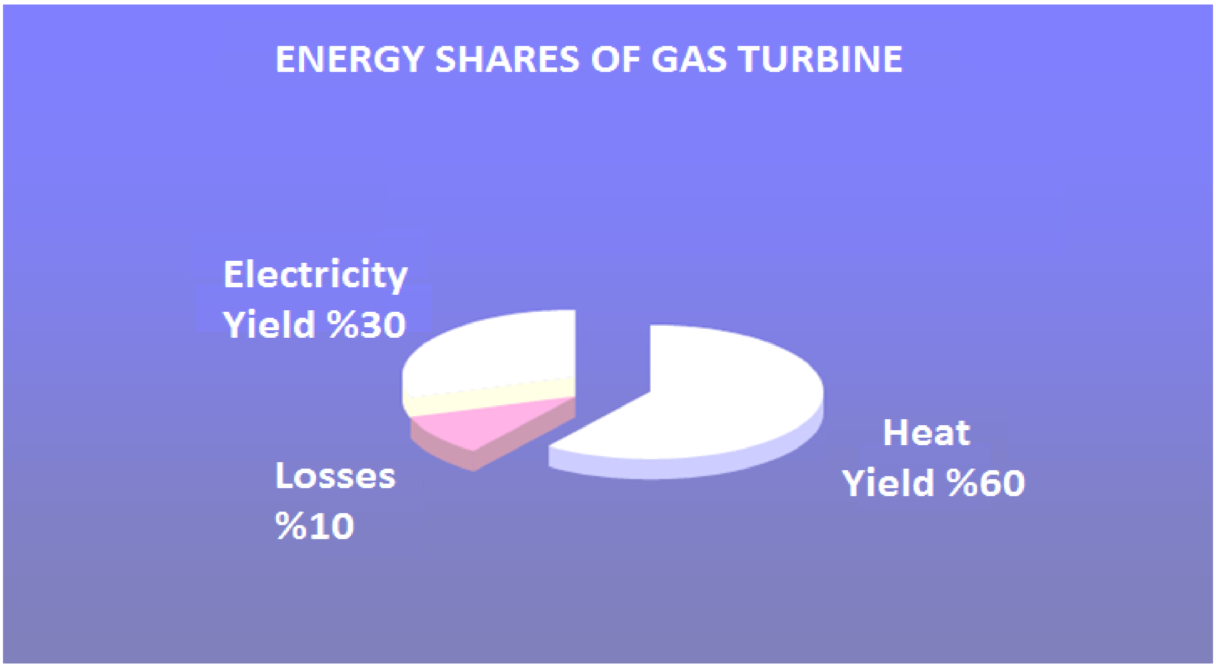

Fig. 4. Energy Shares Of Gas Turbine

These systems provide heat at lower temperatures. They can generate energy in a wide variety of forces. Therefore, it is especially used where the electricity requirement is higher than the heat requirement. (Hotel, ındustry, houses, etc.) (EIO=W/Ql . The ratio of the electricity used to the heat used in the combined heat power plant) The heat energy given to the system in the use of the gas engine for cogeneration (Combined Heat and Power Generation) is obtained from three factors.

These; lubrication cycle of the gas engine, exhaust gases and charge air, cylinder block cooling cycle.

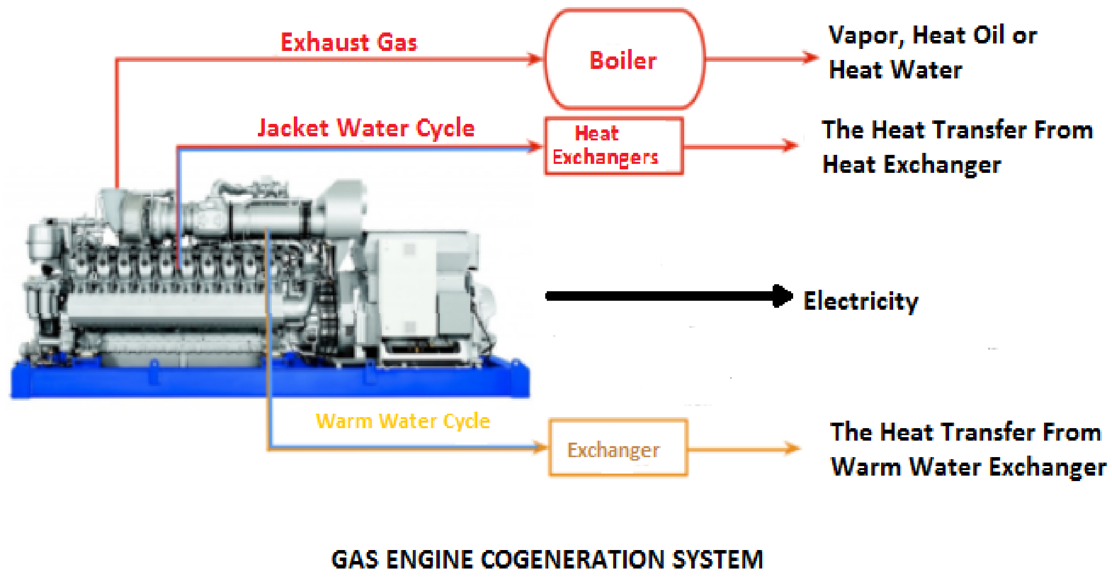

Fig. 5. Gas Engine Cogeneration System [5]

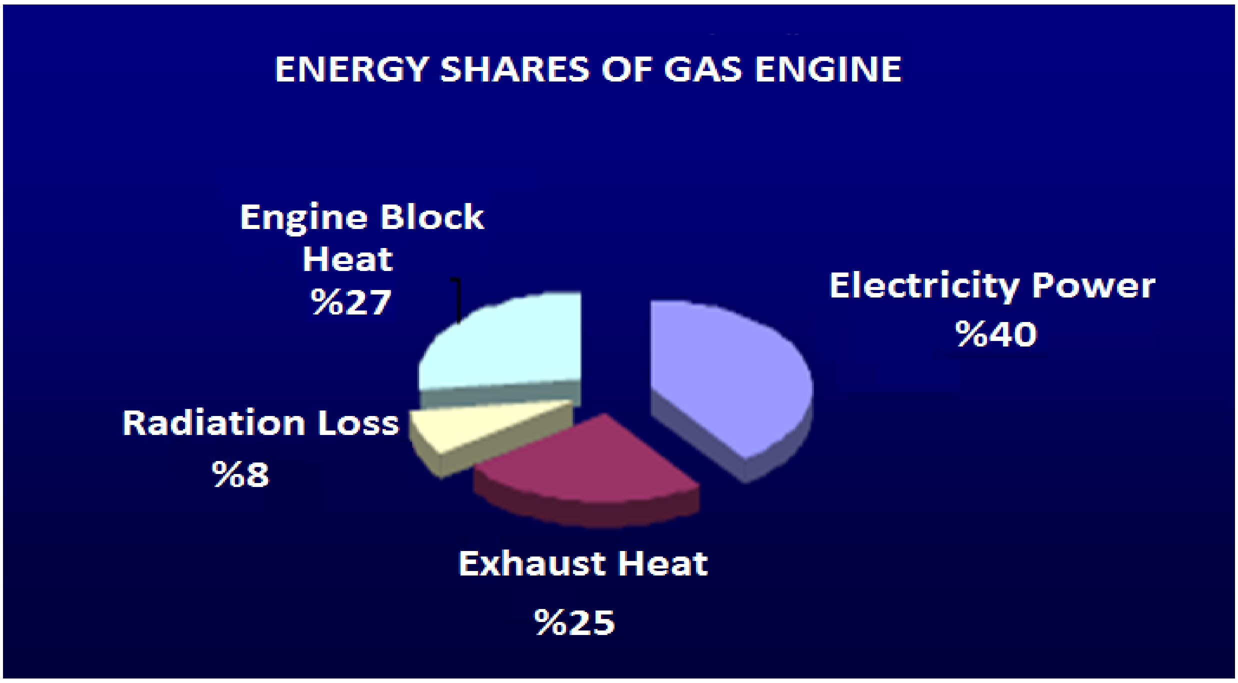

Fig. 6. Energy Shares Of Gas Engine

- **Capacity:**

Gas Turbine:

There are models and brands in gas turbines ranging from 1 MW to 50 MW. If the system is operated as a combined steam gas turbine, systems with power between 10 MW and 100 MW can be built.

Gas Engine:

Power between 4.5W and 20 MW. [7]

Electric Heat Rates :

Electric heat ratios are around 80% in gas engines in gas turbines, EIO is around 40%.

- **Total Yield**

In Gas turbines:

Electricity generation alone: ~ 30%

Combined cycle power generation: ~ 45-50%

Combined power and heat power plant: ~ 85%

Gas engine:

Electrical conversion efficiency: ~ 40%

Total system efficiency: ~ 85-91%

- **Economic Life**

The economic life of cogeneration systems ranges from 100,000 to 150,000 hours. This is equivalent to an average of 12 to 20 years. These systems, which have a lifetime of 12-20 years, self-depreciate in 2-3 years show that these systems are much more advantageous than conventional systems

Cogeneration systems should be selected appropriately, taking into account the economics of the system, the total system efficiency in terms of technique and the requirements of the user. Due to the fact that the cogeneration is a very large investment, a detailed feasibility must first be made. These feasibility results can come before cheapness and quality. Even before the establishment of these systems is decided, the consultant or invertors who work with the organizations will benefit. Otherwise, cogeneration firms direct investors in the direction of the systems and capacities available in their hands.

Parameters to be Evaluated in Cogeneration System Setup

*Fuel * Ambient temperature
* Electric Heat Rate *Total System Capacity
* Load curve *Electricity Quality
* Start Number

Varieties In The Use Of Waste Heat In Cogeneration Systems

- **Ambient heating:** Hot water. steam, hot weather
- **Drying process:** Hot water. steam, hot air or gas
- **Boiler water preheating:** Superheated water
- **Degreasing vc cleaning:** Hot water
- **Process steam collection:** pipe test, toilet etc.
- **Hot heating systems:** Combined cycle power plant
- **Melting (plastic):** Hot oil production
- **Absorption Cooling System:** Climate System

Worldwide Cogeneration Systems

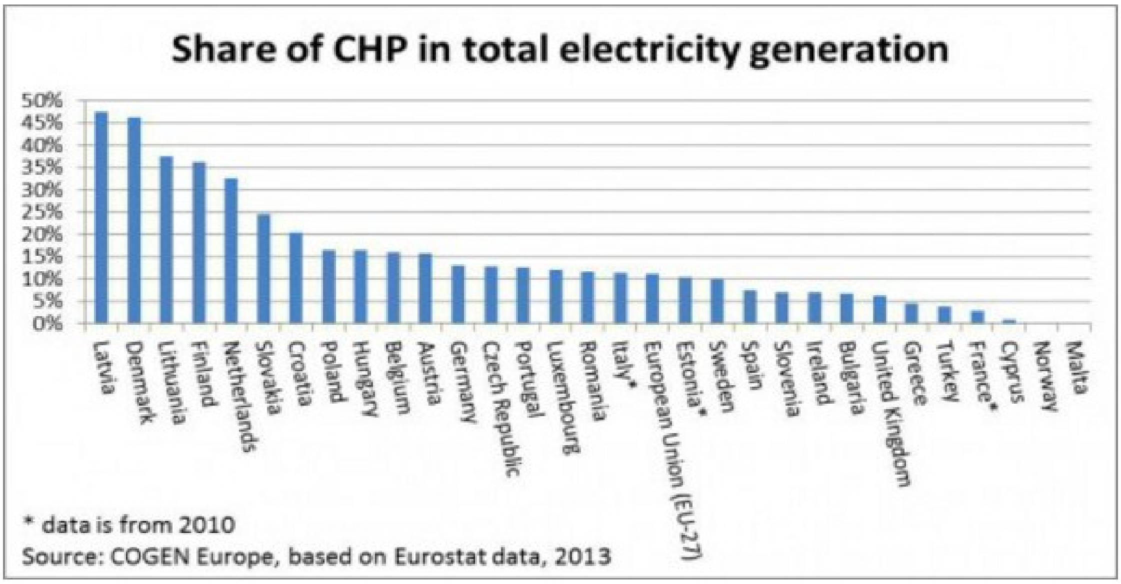

Fig. 6. Usage Ratio of Cogeneration Systems in Electricity Production in the World [8]

CONCLUSIONS

Cogeneration has higher efficiency compared to conventional power plants which produce separately, and they produce more than one type of energy simultaneously with the introduction of a single fuel. Internal combustion gas engines used in cogeneration plants have fast synchronization, flexibility under partial load, good load tracking capability and short payback times. First of all, in large plants where electricity consumption is the basis, it is obligatory to install cogeneration systems with a total efficiency of 80% or more. In addition, in the facilities where the cogeneration system is located, it will not be affected by possible electricity interruptions due to the production-consumption of the energy on site and the production loss, work loss, financial loss and such losses will not be experienced. For these reasons, cogeneration systems are of great importance today.

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Classification of the methods to control metal transfer during gas arc overlaying process

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Summary. A classification of the methods to control the process of metal transfer during gas arc overlaying is presented in the current paper. It is shown that impulse arc process ensure most favorable conditions for control of metal transfer as it is applicable to processing of various metal materials through many combining and hybrid technologies.

Key words: Gas arc welding, metal droplet transfer, process control.

NTRODUCTION

Gas arc welding and overlaying takes a leading place in the economy of countries with higher level of development in Europe, United States, Japan, China, etc., where there are quite large number of researchers working within welding area at point of quality improvement and control of the process during manufacturing of welding constructions or application of additional layers to obtain a specific properties of the metal surface. Most of the main characteristics of the process are determined by the type of metal transfer which affect to the properties of the electric arc as heat balance, dimensional stability, arc length and parameters as well as intensity of metallurgical reactions, spatter loss and formation and shape of applied layers or welding seams. Consequently, the obtaining of qualitative additional layers depends of precision and prompt control of metal droplet transfer through arc column and requires a quite deep knowledge of the essence of metal transfer process [1, 3, 9].

The aim of the current work is to create a classification of the methods for control of metal droplet transfer through the arc column during processing in a gas shield.

EXPOSITION

There are few main metal transfer modes which exists during gas arc welding –small and large globular metal transfers with short-circuits; small and large globular metal transfer without short-circuits and spray-shaped metal transfer as each of them has its advantages and drawbacks. The type of metal transfer depends of many factors as most significant influence is caused by process parameters as composition, type, condition and direction of wire electrode; type of shielding atmosphere; rate, polarity and type of welding current, wire speed, amperage, etc. [3, 9].

The foundation of gas arc processing dates from 50's and there were many systems for control of metal transfer which have been developed and modified since then as they could be divided into three main groups – mechanical, electrical and combined, which are presented in table 1.

The first group includes a mechanical systems, presented as devices for control of wire feeding and gas shield. The group of electrical systems includes devices based on formation of magnetic field or impulse arc, which allows obtaining of variety of algorithms for alteration of arc parameters. Alternatively, the group of combined systems will include the cooperation of both – mechanical and electrical systems.

The mechanical systems for control of droplet transfer are pointed into two directions – to control wire feeding rate and shielding atmosphere. The first group includes all devices which affecting the character of wire electrode feeding at point of impulse feeding of wire electrode, programming of wire feeding rate and applying a vibrations to the wire electrode itself.

The essence of impulse feeding is directed to affix an impulse to the electrode along molten welding pool which causes an additional kinetic energy to the droplet, formed on the top of the wire electrode and detaching of the mentioned droplet from the wire tip and its redirecting to the molten pool. Consequently, this affect to effective and desirable control of metal transfer, especially when short-circuits processing is used [1, 4]. The process could be established through short-timing impulses within constant wire feeding rate or discrete impulses with periodical interruption of wire feeding.

Table 1. Methods for control of metal transfer during gas arc processing

1	Mechanical	Control of wire feeding rate	Impulse feeding of wire electrode
			Programming of wire feeding rate
			Vibrating arc processing
		Control of shielding atmosphere	Gas mixture composition
			Impulse feeding of gas shielding
			Feeding of separated gas streams
2	Electrical	Control of magnetism	Alteration of magnetic field parameters
		Control of impulse arc	Current waves modulation
			Pulsating electric arc
			Impulse alteration of current
3	Combined		

Pulsed wire feeding provide the following advantages: when current at rates from 100 to 400 A is used, the level of sparkling and spattering of molten metal within MAG process decreases almost two times, and welding seams have greater width as well as the transition to the base material is easier which allows an obtaining of metal layers with minimal thickness and higher mechanical properties [8, 4].

The existent mechanisms for pulsed wire electrode feeding could be classified by different indices as according how the wire feeding is established there are draw-in and push-out mechanisms as the first ones takes much more distribution within welding production. Depending on how the mentioned above mechanisms are being powered they could be driven by electric motor or magnet as the first ones could be described as gearless mechanisms driven directly by electric motor; mechanisms with eccentric rollers or profiled cams; feeding mechanisms with stepwise electric motors; gearless mechanisms with valve powering, etc. The gearless mechanisms provides an increased stability of the process and well formed seams, but their value is 1,2 to 1,5 times higher than conventional ones as well as short diapason of frequency, higher level of complexity and impossible control of the parameters during arc processing.

The magnet-driven mechanisms includes one or two magnets accompanied by cylindrical or laminar springs. A main disadvantage of mechanisms with one magnet and spring appears to be ineffective usage of the power of the magnet which is spent not only for wire feeding, but to press the spring as well.

As a drawback of the mechanisms without spring, but equipped with two electric magnets could be noted the lowest temp of increasing of wire feeding and instability of pulse step which affect to frequent adjustment of process parameters.

A programming of wire electrode feeding rate is considered to be a variant of impulse feeding as it is used mostly within short-circuit gas metal arc processing. Its essence consists an algorithm about wire feeding based on pre-programming of power input. The realized short pulses during wire feeding gives an additional kinetic energy to the droplet at the wire tip which causes its detachment and transition to the molten pool [2, 4].

The mechanisms with programmable wire feeding rate gives an opportunities to achieve a significant improvement of the forming and structure of applied layers, low sparkling and spatter loss as well as favorable influence upon energetic characteristics of arc process at point of almost double reducing of consumed electricity (1,3-1,8 times). Their significant advantage is the possibility for adaptation according technological and technical aspects of gas arc process as well as higher stability and repeatability of impulse parameters during wire electrode feeding which affect to lower heat input and thin heat-affected zone [2].

The vibrating arc process consists number of vibrations applied to wire electrode lengthwise or across to feeding direction which affect at point of stable and reliable process. The vibrations are obtained through usage of vibrating spindles which provides lengthwise vibrations of wire electrode which takes wide application because of their simple construction and reliability [11]. The essence of vibrating arc process consist an alteration of short-timing duty cycles (0,01s) which includes both – period of short-circuit and period of arc burning. The presence of short-circuits provides a favorable conditions for small droplet metal transfer, lower heating of base material and very minor temp of increasing of heat-affected zone at higher vibrating frequency. According [10], vibrating frequency at rate of 125 Hz appears to be an optimal for the process.

The main advantages of vibrating arc process could be described as higher productivity based on mechanization of the process; low working values of the voltage (15-20V); producing of applied layers with lowest thickness (0,5-1mm); low penetrating depth and thin heat-affected zone; low heating temperature of base material; lack of deformation; producing of applied layers with higher hardness and processing of details with diameters within 10-15 mm. The main drawbacks of vibrating arc process consists reduced fatigue resistance of the details; presence of cavities in the layers because of rapid cooling; uneven hardness along the applied layer and presence of tiny cracks in the applied metal.

The type and composition of shielding atmosphere causes a significant influence at point of stability of the process, transfer of the molten metal and forming of the applied layers. As it is visible at table 1, the second group of mechanical systems includes devices which allowing changes into composition, type and directing of shielding atmosphere as variable gas mixture composition; impulse feeding of the gas shield or using a separate gas streams.

The control of gas mixture composition consists usage of different type of shielding gases as argon, carbon dioxide, oxygen and others in variable percentage between them within any given mixture. The difference in ionization potential, heat and electro conductivity as well as their density determinate their shielding properties and affect to arc burning process. Because of discontinued application of new gas arc processed materials there is a necessity of new shielding mixtures of inert and active shielding gases. An addition of 10-40% CO_2 and/or 3-5% O_2 affect to achieving of higher processing speed; more stable process; reduced sparkling and spatter loss accompanied by small droplet metal transfer through arc column [6].

Impulse feeding of shielding gases is a new method based on pulsations of gas stream, especially within argon-helium mixture. Compared to the conventional methods without pulsations, the new technology provides applied layers without any defects. Thanks to the pulsation of gas stream pressure caused by ionization differences of argon and helium a shock impact is established upon molten pool which provides low-grain structure as well as high ductility and strength of the applied metal layer [2].

Applying of separate streams of shielding gases gives another possibility for control of metal transfer, welding seam shape and penetration depth. A special nozzle is used for this purpose which includes outer and inner nozzles to directing both streams of shielding gases. Normally, stream of inert gas or mixture of inert gas and small percentage of active gas is passing through inner nozzle as independent stream of active shielding gas is directed through outer one. Consequently, the inner stream provides an immediate shield of the electric arc and molten pool, but the outer stream improve the shield of welding zone and cooling seam as the shielding properties of used gases are main factor for high quality of the applied layers. Processing with separate streams of 25% Ar and 75% CO_2 provides very good stability of the process at point of stable electric arc, spray metal transfer and low spattering which does not established when a gas mixture with same composition is used [7]. Thus, processing with usage of separate streams of shielding gases leads to lower consumption of inert gas which affect to low cost of restored details.

The electrical systems for metal transfer control includes two directions – control based one alternating magnetism and usage of impulse arc. The essence of first group consists usage of magnetic field.

The control of the process through applying of **magnetic field** is based on affixing of electromagnetic pulses to the arc which affect to the type of metal transfer and its alteration from large globular into spray metal transfer [2]. An increasing of electromagnetic pulse frequency and alteration of their shape leads to increase of the number of transferred droplets and decrease the level of spattering.

To the group of methods for control based on impulse arc action belong devices which affect to electrical parameters of the process through modulation of current loop; arc pulsation or applying of impulse alteration of working current.

By modulation of current loop is possible to achieve the following aims – control of metal transfer, higher stability of the process, lower spattering, control of crystallization speed and direction of growing of the metal in the welding pool and heat-affected zone as well as better forming of weld seam [8].

Processing wherein a pulsing electric arc is used consists a special welding process with spray metal transfer which provides greater technological possibilities as high voltage pulses cause greater penetration depth, but do not allow exceeded heating of the base material. In comparison to processing with constant arc, the pulsing arc increases the process of mixing between base and filler metal without increasing of base material temperature [2, 8].

The metal transfer within pulsating electric arc is established through impulse alteration which causes detachment of droplets from wire electrode tip as it is possible to control their size and frequency. Such metal transfer is used not only for welding, but either – establishing of transitional metal transfer modes and new hybrid welding technologies [1, 5]. In a role of power supply an invertors are used which provides different loops of working current and control of amplitude, frequency and duration of current pulses [1].

Impulse arc welding process consist some significant technological advantages compared to conventional gas arc welding process resulting in preciously controlled and directed metal transfer; lower sparkling and spatter loss; increased productivity from 3 to 8 times; reducing of welding stresses; applying of longer arc length within low rates of process parameters; high quality of the applied layers because of thin heat-affected zone and favorable conditions for crystallization process; easier arc burning; healthier working environment, etc. The method is suitable for welding of various grades of steel, copper, nickel and aluminum alloys as well as titanium alloys within wide range of thickness and all welding positions [8].

CONCLUSIONS

1. A classification of the methods of control the process of droplet transfer from wire tip end to molten pool during gas metal arc processing is done.

2. The control of the process of metal transfer through the arc column could be established based on control of impulse arc parameters by usage of various types of mechanical and electrical systems.

3. At the present time, impulse arc welding provides best conditions for control of metal transfer as it could be applied when a processing of wide range of materials is necessary within appropriate combined and hybrid technologies

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Building probabilistic reliability models in case of sudden failures

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Summary. The article describes the main theoretical propositions of the methodology to predict mechanical reliability under conditions of repeated exposure to random extreme loads. The mechanical load process is considered to be a form of a discrete sequence of loads occurring at times that form a random flow. It is being solved some problems of reliability prediction of elements having deterministic or random bearing capacity. A method for the probabilistic justification of the reserve coefficients is developed, providing a predetermined level of reliability of elements and systems for sudden failures when designing. It is considered the methods of prediction and management of reliability under conditions of using safety devices. The main theoretical results are presented in a form available for practical engineering applications.

Key words: reliability, mechanical reliability prediction, random extreme loads, sudden failure, reliability control.

INTRODUCTION

The article is devoted to a brief review of the fundamentals of one of the many directions of science of reliability - predicting risks of sudden mechanical failures and associated reliability indicators. Theoretically, there are also promising ways to manage and ensure reliability under repeated extreme loads. They are based on stochastic models of emerging and preventing from sudden mechanical failures, typical for parts of mobile machines. It is possible to use the methods described when predicting reliability of building structures. The conceptual feature of setting tasks of mechanical reliability is to ensure the bearing capacity of structures in time.

A probabilistic approach to reliability prediction is widely used, which corresponds to the stochastic nature of the influencing factors and causes of sudden mechanical failures. The article develops a method of probabilistic substantiation of the value of the safety factor under repeated loads, which refers to the ratio of the average values of the bearing capacity of elements and extreme loads. This allows to carry out such a substantiation objectively, on the basis of studying and analyzing test results and real statistical data on loads and on dissipating the bearing capacity of structural elements. This way seems to be more progressive than the method of expert appraisal of safety factors, that has been used up to now; which normative documents commonly used in designing in various sectors and departments are based on it.

The safety factor is a generalized parameter that in many respects determines the future material consumption and the cost price of the designed product. Therefore, dependencies linking the safety factors of the machine parts with the predicted reliability indexes allows, at the design stage, to choose a rational and economically feasible option to ensure a sufficient level of reliability.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Ensuring the reliability of machinery elements from sudden mechanical failures under the traditional deterministic approach to design calculations is reduced to the use of safety factors [1]. Their purpose is to take into account and compensate the influence of various random factors on mechanical characteristics of materials and the magnitude of operating loads. Thus, the influence of randomness when reliability is being provided is actually recognized, however, probabilistic models and methods are not used to account this influence. The safety factor is specified in the technological normative documents or standards used in various branches of engineering. Their value is usually established empirically on the basis of expert analysis and generalization of previous experience in the design and operation of products of a similar purpose.

As a rule, with this approach, it is impossible for an engineer to determine which failure risk of the projected object corresponds to the recommended standard value of the safety factor. He does not receive information about how the operation time of an object, its structure and the number of elements it consists of, affect failure risks. In connection with these drawbacks, the use of stochastic (probabilistic and statistical) concepts and corresponding models is more progressive when predicting reliability. We should point out a number of advantages of the probabilistic approach to justification of the safety factors [2, 12, 13, 14, 15] over deterministic ones.

THE MAIN RESULTS OF THE RESEARCH

Fig. 1. shows the scheme of superposition of additional non-stationary extreme loads on the main stationary mode. Extreme load is a load potentially capable of leading an element to sudden destruction or unacceptable deformation. In practice, this means that the extreme load may exceed the lower limit of the random dispersion of the bearing capacity. A value of the random extreme load P_l is determined by the difference between

the maximum of the extreme load and the lower limit of the distribution of the bearing capacity $\widetilde{P}_o$, which is a conditional non-damaging level. In practice, such a level can be taken, estimating it indirectly, as the upper limit of the range of possible values of the main constantly operating stationary loading process. For example, using the known "three sigma rule", we can assume that $\widetilde{P}_o = \overline{P} + 3\sigma_V$. Usually, such an approach, by somewhat understating the estimate of the non-damaging level, provides the possibility of guaranteed lower-level estimation of the probability of uptime under repeated actions of extreme loads.

The schematization method of the object's external extreme loads used to built reliability models implements a popular approach [3, 15, 16], which consists in replacing the continuous random loading process by a discrete sequence (flow) of stochastically independent random by size and identically distributed [26] influences $P_{\text{н}1},\ldots,P_{\text{н}m}$ at random times $t_1,\ldots,t_m$. The corresponding scheme of the stationary discrete flow is shown in Fig. 1., b. Considering that in practice, when mobile equipment is used, extreme loads occur rarely, and the danger of sudden quasi-static destruction is mainly determined by the maximum value of equivalent stresses that arise during short-term loads; this way of schematizing the extreme load can be considered reasonable. Its use when reliability models are designed greatly simplifies the mathematical apparatus and in a number of cases allows you to obtain results in an analytical form important for engineering calculations.

Fig. 1., b shows: $g(P_{\text{п}})$ distribution density of the random bearing capacity; $f(P_{\text{н}})$ -distribution density of random extreme loads.

There is a rational approach, which makes it possible for the probabilistic justification of the safety coefficients and obtaining practically realizable recommendations. This approach consists in refusing to use the assumptions about their randomness when loads are schematized, but in specifying a type and parameters of the assumed law of distribution of random extreme effects. In this case, it is expedient to use the distribution functions of continuous positive random variables with a unimodal (single-vertex) density and an infinite upper bound for random scattering. At the design stage, the main and most informative parameter that determines the level of random dispersion of the load or bearing capacity for machine-building reliability calculations [9] is the dimensionless variation coefficient. Therefore, it is preferable to apply two-parameter distribution laws. In the future when constructing models the following laws are widely used: the Weibull distribution law in the form [19], as well as the log-logistic distribution [4] and the Frechet distribution [5]. The application of normal [18], log-normal [13], and double exponential [6] distributions is traditional.

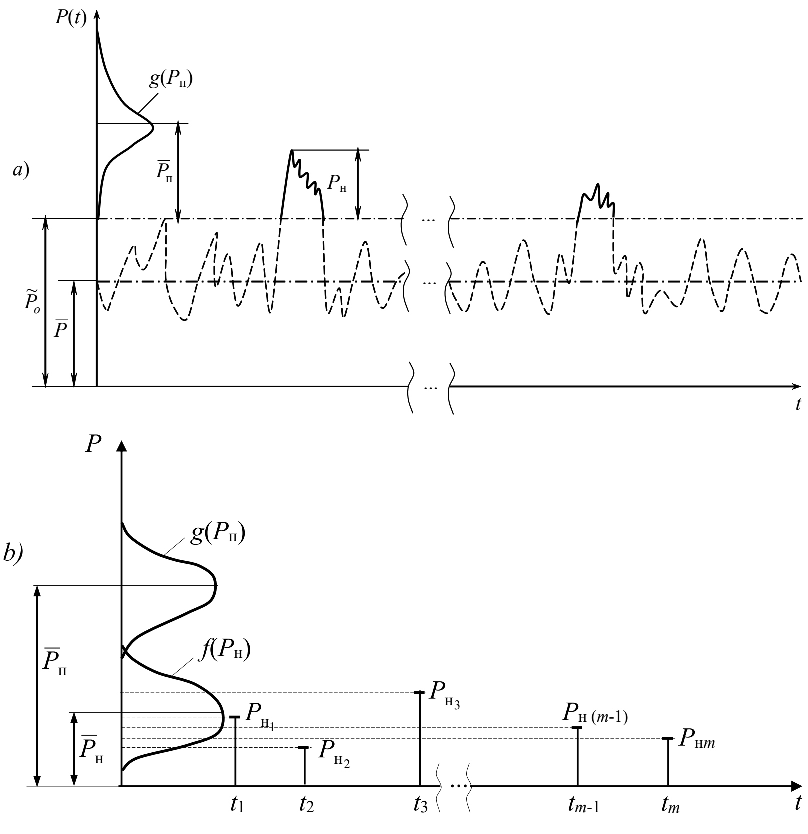

Fig. 1. Schematicization of multiple extreme loads:
a) imposition of extreme loads on the stationary mode; b) a scheme of a random stationary flow of independent discrete loads.

If the load distribution function for any extreme load $F(P_{н})$ is given and does not depend on the operating time and the number of extreme loads m, the reliability function R_1 with a single (first) load of the element can be determined as the probability of $P_{н} < P_{о}$ or

$$R_1 = F(P_{о}). \quad (4)$$

In a general case, at m repetitive extreme loads, the reliability function is determined by the probability that the constrained maximum of the m-multiple load $P_{\max}(m) = \max(P_{н1},\ldots,P_{нm})$ does not exceed the constant limit level $P_{о}$ of the bearing capacity of the element. The theory of extreme values of identically distributed independent random variables [6, 26] proves that the distribution functions of the constrained maximum $F(P_{\max}(m))$ and loads $F(P_{н})$ must be related by the dependence.

$$F(P_{\max}(m)) = F^m(P_{н}). \quad (5)$$

Then the reliability function of an element when it is subjected to *m*-repeated extreme loads is given by the following expression:

$$R_m = F^m(P_{о}) = R_1^m = (1 - Q_1)^m, \quad (6)$$

where: Q_1 is a probability of failure at the first load.

It follows from (6) that the number of extreme loads m to a sudden mechanical failure at a deterministic constant limiting level of the bearing capacity of an element has a discrete geometric distribution [8, 22]. The probability function of failure at *m* loading or the discrete density of this distribution:

$$Q_m = R_{m-1} - R_m = Q_1(1 - Q_1)^{m-1}. \quad (7)$$

The average number of extreme loads to failure:

$$M = \frac{1}{Q_1}. \quad (8)$$

In this case, the discrete analogue of the intensity of sudden failures (the risk function) is defined by the expression: $\lambda_m = \frac{Q_m}{R_{m-1}} = Q_1$ and does not depend on m.

On the assumption of the fact that at a deterministic (nonrandom) limiting level of the bearing capacity of an element, the number of loads prior to a sudden failure has geometric distribution. It is possible, using various laws of distribution of a random load, to obtain analytical expressions for predicting the indicators of mechanical reliability.

The transition in the measurement of the volume of the produced resource from the number of extreme loads m to the operating time t can be carried out by accepting certain assumptions about the type of a random flow of instants of discrete loads (see Fig. 1.b). In many cases, assuming the independence of random operating times before loading, $t_1, t_2, ..t_m$ the assumption of a stationary Poisson flow is acceptable, where the density of the distribution of the number of loads i per the operating time t has the form

$$P_i(t) = \frac{e^{-\frac{t}{T_o}}}{i!} \cdot \left(\frac{t}{T_o}\right)^i, \quad (9)$$

where: T_o an average period between random loads.

Then, based on the well-known formula for full probability, we have an expression that determines the reliability function as a function of the safety factor and operating time:

$$R(K,t) = \sum_{i=0}^{\infty} P_i(t)\, R_i(K), \quad (10)$$

where: $K = \frac{\overline{P}_n}{\overline{P}_н}$ – element safety factor; $\overline{P}_n$ и $\overline{P}_н$ – average load carrying capacity and extreme load, where, in accordance with (6), conditional reliability function $R_i(K) = R_1^i(K)$ – a conditional reliability function for a random number i of loads.

From (9) and (10) it follows that the operating time to failure as an exponential distribution in this case, and the reliability function is determined by the expression:

$$R(K,t) = \exp\left(-\frac{t}{T_o}(1 - R_1(K))\right). \quad (11)$$

In this case, the mean time to failure is determined by the formula

$$T = \frac{T_o}{1 - R_1(K)} = MT_o, \quad (12)$$

and the failure rate is independent of the operating time constant:

$$\lambda = \frac{1 - R_1(K)}{T_o} = (1 - R_1(K))\,\omega_o, \quad (13)$$

where $\omega_o = 1/T_o$ is a constant rate of extreme loads.

Expression (13) indicates that for the constant nonrandom bearing capacity and a stationary Poisson load flow, the stream of sudden failures in the set of elements is also a stationary Poisson flow, but with a reduced rate.

When using different types of distributions of random load values and the bearing capacity of the elements to predict the reliability function at the first load, the following expressions [15, 20, 24, 25, 27, 28] are widely used:

$$R_1 = \int_0^{\infty} F(P) g(P)\, dP, \quad (14)$$

$$R_1 = \int_0^{\infty} [1 - G(P)] f(P)\, dP = 1 - \int_0^{\infty} G(P) f(P)\, dP, \quad (15)$$

where: $F(P)$ and $f(P)$ - a function and a density of the load distribution; $G(P)$ and $g(P)$ -a function and density of the bearing capacity distribution.

Formulas (14) and (15) assume that the load and the bearing capacity are independent random variables. The meaning of the formulas are equivalent and the choice between them is determined only by the ease of use for specific types of distributions.

Let us consider the most frequently encountered variant of the randomness of the quasi-static bearing capacity of machinery elements and structures, which consists in the fact that the random bearing capacity of each element is determined only by its initial quality and practically independent of the operating time or number of loads to which the element was subjected. In this case, the form and the distribution parameters of the bearing capacity do not depend on the operating time. If loading occurs repeatedly and the bearing capacity of the element is a random variable that does not change in time, then proceeding from the fact that the distribution function of the maximum of the discrete random sequence of loads $P_{н_1},\ldots,P_{н_m}$ (see Fig. 1.1b) in accordance with (5) is expressed as $F^m(P)$. By analogy with (15), one can obtain [15] an expression for the reliability function of an element with m-fold loading:

$$R_m = \int_0^\infty F^m(P) g(P)\, dP. \qquad (16)$$

Taking into account that the density distribution of the maximum of the random load sequence is as follows:

$$f(P_{\max}(m)) = \frac{dF^m(P)}{dP} = mF^{m-1}(P) f(P), \qquad (17)$$

By analogy with (15), we obtain the equivalent expression (16) for the reliability function:

$$R_m = m\int_0^\infty [1 - G(P)]\, F^{m-1}(P) f(P)\, dP. \qquad (18)$$

The reliability models (16) and (18) assume that for each element its random bearing capacity is realized only once, remaining a fixed value in time in the process of loading this element. The random load acting on the element is implemented m-fold, forming a random discrete sequence of independent quantities (Fig. 1., b). It is also assumed that the load distributions and the bearing capacity do not depend on time (operating time).

Practical application of models of the form (14), (15), (16), and (18) can be simplified using a transformation, called a transition to unit distributions [10, 11]. Expressions (14) and (15) can be rewritten in the form

$$R_1 = \int_0^\infty F(P)\, d\, G(P), \qquad (19)$$

$$R_1 = 1 - \int_0^\infty G(P)\, dF(P). \qquad (20)$$

Obviously, for the transition to (19) from integration over a variable *P* to integration over a variable G, it is sufficient to eliminate a variable *P* in $F(P)$, expressing it with the help of a quantity *G*. We denote by the symbol $\psi(G)$ the function inverse to the distribution function of the bearing capacity $G(P)$. This function determines the magnitude of the quantiles of the bearing capacity distribution $P_G = \psi(G)$ that correspond to a probability G. We will call it the inverse distribution function of the bearing capacity. The variable G varies in the unit interval: $0 \le G \le 1$. Therefore, the complex function obtained by substituting for the load distribution function $F(P)$ instead of its argument P of the inverse bearing load distribution function $\psi(G)$ will be called the function of the unit load distribution:

$$F_1(G) = F(\psi(G)). \qquad (21)$$

An essential feature of the distribution resulting from such a transformation of distribution is that it has not only a function, but the argument varies in the interval from zero to one. Therefore, the expression (19) for a reliability function of the element at the first load after the transition to the unit load distribution takes the following form:

$$R_1 = \int_0^1 F_1(G)\, dG. \qquad (22)$$

The transition to unit distributions depending on which function of unit distributions – $F_1(G)$ or $G_1(F)$ is more convenient to use, also transforms the general expressions (16) and (18), which gives four versions of equivalent formulas for the reliability function of an element under *m*-fold loading:

$$R_m = \int_0^1 F_1^m(G)\, dG = \int_0^1 F^m g_1(F)\, dF; \qquad (23)$$

$$R_m = 1 - m\int_0^1 G F_1^{m-1}(G) f_1(G)\, dG = 1 - m\int_0^1 G_1(F)\, F^{m-1}\, dF, \qquad (24)$$

where: $f_1(G) = \dfrac{dF_1(G)}{dG}$ – a density of the unit load distribution;

$g_1(F) = \dfrac{dG_1(F)}{dF}$ – a density of a single distribution of the bearing capacity.

For various types of load distributions and bearing capacity, forecasting the probability of fail-safe operation can always be performed by numerical integration of expressions (23) or (24) on a finite (unit) interval [9]. In some particular cases, it is easier to obtain analytical results by the method of transition to unit distributions (21).

Let us consider some examples of using the method of single distributions. If the Weibull law is used as the functions of load distribution and bearing capacity:

$$F(P) = 1 - \exp\left[-\left(\frac{P}{a_н}\right)^{b_н}\right];$$

$$G(P) = 1 - \exp\left[-\left(\frac{P}{a_п}\right)^{b_п}\right], \qquad (25)$$

then the inverse load distribution function $\psi(G)$ will have the form

$$\psi(G) = a_{п}\left(\ln\frac{1}{1-G}\right)^{1/b_{п}}. \quad (26)$$

Then the function of the unit load distribution is determined from the expression:

$$F_1(G) = 1 - \exp\left\{-\left(\frac{a_{п}}{a_{н}}\right)^{b_{н}}\left(\ln\frac{1}{1-G}\right)^{b_{н}/b_{п}}\right\}. \quad (27)$$

In the particular case where the random variables and bearing capacity similar to [17], and the coefficients of variation of the bearing capacity and equal or close in magnitude: $b_{н} \approx b_{п} = b$, then the safety factor by average $\overline{K} = \frac{a_{п}}{a_{н}}$. Then the expression for the function of the unit load distribution becomes simpler and takes the form

$$F_1(G) = 1 - (1-G)^{\overline{K}^b}. \quad (28)$$

Determining the reliability function at the first load from (22), we obtain that

$$R_1 = \int_0^1\left[1-(1-G)^{\overline{K}^b}\right]dG = 1 - \int_0^1 (1-G)^{\overline{K}^b}\,dG. \quad (29)$$

The integral in (29) is calculated by changing the variable $x = 1 - G$, which gives the formula:

$$R_1 = \frac{\overline{K}^b}{\overline{K}^b + 1}. \quad (30)$$

Assuming that the load and the bearing capacity have a Weibull distribution (25), the inverse load distribution function $\varphi(F)$ takes the form

$$\varphi(F) = a_{н}\left(\ln\frac{1}{1-F}\right)^{1/b_{н}}, \quad (30)$$

and the function of the unit distribution of the bearing capacity is determined from the expression:

$$G_1(F) = 1 - \exp\left\{-\left(\frac{a_{н}}{a_{п}}\right)^{b_{п}}\left(\ln\frac{1}{1-F}\right)^{b_{п}/b_{н}}\right\}. \quad (31)$$

In the particular case at $b_{н} \approx b_{п} = b$ when we get that

$$G_1(F) = 1 - (1-F)^{1/\overline{K}^b}. \quad (32)$$

Substitution of (32) into the second version of formulas (24) gives an expression for the reliability function for *m*-fold loading

$$R_m = m\int_0^1 F^{m-1}(1-F)^{1/\overline{K}^b}\,dF. \quad (33)$$

The integral on the right-hand side of (33) is a beta function [22]. Consequently

$$R_m = m \cdot B\left(m, 1 + 1/\overline{K}^b\right). \quad (34)$$

Expressing the beta function with the help of gamma functions, we obtain an analytical dependence [7] for the reliability function

$$R_m = \frac{\Gamma(m+1)\Gamma\left(1 + 1/\overline{K}^b\right)}{\Gamma\left(m + 1 + 1/\overline{K}^b\right)}. \quad (35)$$

Taking into account that the following formulas are relevant for integers m:

$$\Gamma(m+1) = m!; \quad (36)$$
$$\Gamma\left(m+1+1/\overline{K}^b\right) = \Gamma\left(1+1/\overline{K}^b\right)\cdot\prod_{i=1}^{m}\left(i + 1/\overline{K}^b\right),$$

substituting them into (35), we obtain an expression for the reliability function under repeated loads, which is convenient for practical use in engineering calculations:

$$R_m = \prod_{i=1}^{m}\frac{i\overline{K}^b}{i\overline{K}^b + 1}. \quad (37)$$

CONCLUSIONS

Based on the above, we have the following conclusions:

1. In the case of the stationary Poisson flow of extreme loads and deterministic bearing capacity, the flow of sudden failures will also be Poisson with a reduced intensity depending on the safety factor.

2. The randomness of the bearing capacity and the actual load leads to the use of the method of unit distributions when building reliability models. This makes it possible to obtain analytical expressions for the probability of no-failure in case of sudden failures.

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Modeling of utilization means of oilseed flax stem part

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Summary. The paper shows the results of modeling of the means of processing and recycling of Oilseed Flax harvest stalks. An algorithm which describes the technological process of harvesting Oilseed Flax and processing it into fuel materials is proposed. The evaluation of consumer properties of Oilseed Flax fiber indicates its significant potential as a raw material for textile industry. However, the difficulties that arise in stalking the stems in a stock require the search of new ways of using pulp, which is formed in the process of gathering Oilseed Flax by a combine harvester.

Keywords: Oilseed Flax, Stems, Cutting Surface, Cutter Tooth Model, Destruction, Processing Technology, Utilization.

INTRODUCTION

The development of organic production and the implementation of legislation on the utilization waste of European Union [1] in Ukraine envisages a search of ways and means of processing and disposing of the unproductive part of industrial crops, particularly Oilseed Flax.

The utilization by burning the stem part of Oilseed Flax during its harvesting is a problem of agricultural production in Europe. Burning is unacceptable in the global warming conditions; it also does harm to the environment, since soils are clogged with the fibrous component of the stems, which does not decompose for a long time. In this regard, the problems with the qualitative use of land resources arise. During the gathering of Oilseed Flax with a modern combine harvester, straw rolls remain in the field. They are of considerable size and, as a result, they do not turn into stock for a long time by means of a retting.

Therefore, it is advisable to dispose of the stem part of the Oilseed Flax harvest by its processing in stationary conditions to obtain products for various purposes.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Scientists are actively researching the ways to process and utilize the stem part of industrial crops. A study of consumer properties of Oilseed Flax fiber grown in the conditions of Western Polissya showed [2, 3] that they do not differ significantly from the properties of Fiber Flax. However, the problem lies in the technical means for gathering Oilseed Flax in order to use the maximum potential of the plant - after the separation of seeds, to ensure the mechanization of the processes of formation of stock, its timely selection and processing.

The considerable attention is paid to creating the conditions for preparing stock from flax stems to preserve the quality properties of the fiber, [4, 5,] in accordance with the natural-climatic growing conditions. In particular, scientists of Kherson National Technical University conducted the research on the artificial moistening of Oilseed Flax straw with various chemical reagents to accelerate the laying of stock and the increase in consumer properties of the resulting short non-oriented fiber [6]. But today there are no studies on the production of fiber from Oilseed Flax by the method of retting.

A possible way of solving the problem is also the search of new types of fuel materials [7, 8 - 11]. The peculiarity of producing fuel from such raw materials is their sealing by known methods. It is necessary to apply the appropriate boilers for their use. Oilseed Flax, grown on the territory of Western Polissya, has a powerful energy potential. The scientists of Lutsk National Technical University conducted the research on the production of fuel materials in the form of briquettes by using frozen lacustrine sapropel as a binder. As a result of study the energy potential of the samples and the time of their combustion were obtained. [10].

The presence of short Oilseed Flax fiber in fuel materials complicates the manufacturing process in the form of packages suitable for combustion in serial boilers due to the considerable elastic properties of the stems. However, the production of such fuel bags will allow using of the fiber which not suitable for using in the textile industry. The lack of specialized machines for a given crop leads to significant loss of yield. First of all a significant damage to the stem part of the crop, which affects negatively the fiber production; causes the loss of seeds; stubble that stays in the field, contains fiber and negatively affects the further use of the field; The winding of stems on the working bodies leads to the faults of the combine.

Mechanical damage to the bast part of the Oilseed Flax stems when it is harvested for seeds will accelerate the transformation of the stems into the stock. The use of effective mechanical impact on the processing stage of the stocks will allow the shortest unoriented fiber to be identified as much as possible. The study of the destruction of leaf-stemmed agricultural materials [12-14] indicates the prospect of destruction of the stem part of flax by oil-based mechanized means with rotor drums [12-14]. However, the research on the grinding process of the stem part of Oilseed Flax, grown in the conditions of the Western Polissya, is not available today. Therefore, if the processing of the stem part of Oilseed Flax is to be carried out within certain timeframes, it is possible to obtain good fibrous raw materials for the textile industry. If the stalks lose their quality, it is possible to obtain materials suitable for the manufacture of fuel, geotextiles, building materials, etc. This will help to solve many environmental problems.

The purpose of the research is to prove the possibility of efficient use and ecological utilization of the stem part of the crop of Oilseed Flax grown in the agro-climatic conditions of the Western Polissya. To achieve the goal, the design of the apparatus for the grinding of the bast part of technical crops by cutting method was substantiated and simulated, and a numerical model for determining the profile of the Cutter Tooth was developed.

RESEARCH METHODOLOGY

The Oilseed Flax gathering is associated with its ripeness and, with the condition of the ripening of the seminal part in the phases of early or early yellow ripeness; segmental-finger cutting devices are used. In this paper, particular attention is paid to the amount of stem cutting effort for three positions: compartment, middle and upper. At the same time, the initial relative humidity of the stems ranged from 13-15% for the stock and 21.8% of the stems in early ripeness. The cutting force of the stems was determined with the help of the developed laboratory stand. (see Fig. 1).

Fig. 1. The laboratory stand for researches

Thus, the technical means should predict the possibility both of cutting the Oilseed Flax stems and the pulling. The complexity of obtaining raw material for fiber from the Oilseed Flax stems occurs at the stage of its harvesting. The fiber is directly dependent on the natural and climatic conditions in a certain period, the conditions for obtaining the stock and the proper amount of technical means.

Cad-systems, in particular, "KOMPAS" and "AutoCad", were used for the development of a 3D volumetric model of grinding tools for Oilseed Flax and a profile of Cutter Tooth. Mathematical modeling of the process of plant papers transferring to the surface of the Cutter Tooth was based on the theory of differential equations of motion of a point with rough surfaces. A numerical experiment by means of the developed mathematical models was performed in the mathematical package MathCad. The solution of the differential equations was based on the numerical Runge-Kutta calculation method of the 4th order. To verify the results of theoretical studies, a laboratory plant (see Fig. 2) was used to obtain well-shredded stems.

a)

b)

Fig. 2. General view of the laboratory plant for grinding Oilseed Flax (a) and the position of cutting knives in the body (b)

RESULTS

The problem of transforming the stem mass into the stock arises just at the flax harvesting stage with an Oilseed Flax combine harvester (see Fig.3), when a roll of stalks with dimensions in the cross section in the range of 1.0 × 0.5 m is formed in the field. From Fig. 3 shows that the stems in the rolls are chaotic. This makes it difficult to use the rotation operation while converting them into a stock. Also, the terms for harvesting Oilseed Flax depend on weather conditions and, as a result, there will be a different phase of ripeness of the crop. Therefore, the quality of the fiber will be different. The results of the determination of the complex quality index for fiber from Oilseed Flax grown in the conditions of the Western Polissya in the phase of early yellow ripe-ness (Fig. 3a) and the comparison with Flax fibers indicates the prospect of using Oilseed Flax fiber in the textile industry [3]. However, the harvesting of Oilseed Flax in the phase of full ripeness (see Fig. 3b) indicates a loss of quality of the stem mass and the quality of the fiber.

a) b)

Fig. 3. Rolls of Oilseed Flax made by a combine harvester at different phase of ripeness: a) early yellow ripeness; b) - ripeness

For effective destruction of the stem part of Oilseed Flax, a mechanical device with rotor drums has been proposed (see Fig. 4) [15…18]. It includes two main assemblies placed on the frame 1: shaper 2 of layer 3 takeoff reel 4, rolls 5 and 6 and rotor 7 with knives 8 with worksurface 3.

Experimental verification of the proposed types of knives proved the effectiveness of the destruction of Oilseed Flax stems, taking into account the phase of ripeness and further usage of the fibrous mass. To reduce the elastic properties of the stems at the stage of converting them into a stock, it is possible to use hammer-type knives. Then the awn is partially removed from the stems, and the height of the roll is halved, which contributes to the intensive penetration of moisture from both the field surface and the environment, ensuring the intensive development of pectin-destructive bacteria.

For high-quality operation of the device for grinding bast raw materials, it is important to ensure the working conditions of the mechanism. Thus, it is necessary in this way to select the e-dimensions of the Cutter Tooth and the kinematic parameters of the rotor, which will guaranteed the grinding of the stem in the cutting zone that. This zone is characterized by the trajectory by which the conventional stem moves, which is located on the working surface of the knife from the pickup, point A_1 of the material to the point A_2. The point A_2 is the extreme point where the stem breaks down (see Fig. 5). The provision of this condition is possible with the appropriate rotor tooth profile. Since in the cutting zone, the stem section has a diameter in the range of 1 ... 2 mm, the process of its movement can be described as the movement of a material paper M on a rough surface. We introduce a coordinate system YOX with a center at the top of the Cutter Tooth and suppose that the rotor is stopped and does not rotate, and the plant material moves along the Cutter Tooth surface and rotates around the axis O_1 at the same time. In this case, the material paper M will carry out the transport motion - rotational with angular velocity ω, and the relative motion - translational linear velocity V_r.

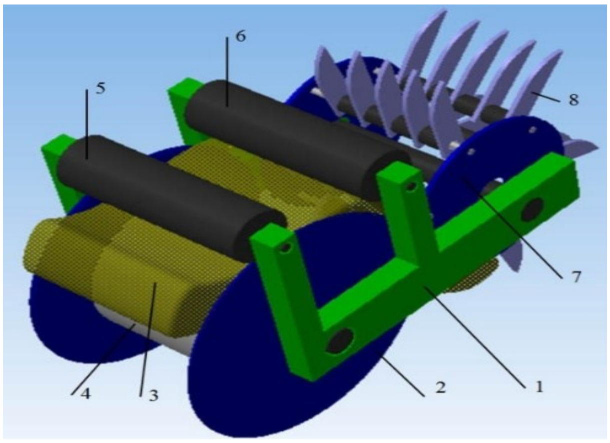


Fig. 4. The plant scheme of stem mass destruction

In addition, the following assumptions must be made to solve the problem:

- the material paper moves from point A_1 to point A_2 during the turn from position $\varphi = \pi/2$ to position $\varphi = 0$;

- the movement of a material paper M on the working surface of the Cutter Tooth occurs in proportion to the change in the angle φ of the rotation of the drum.

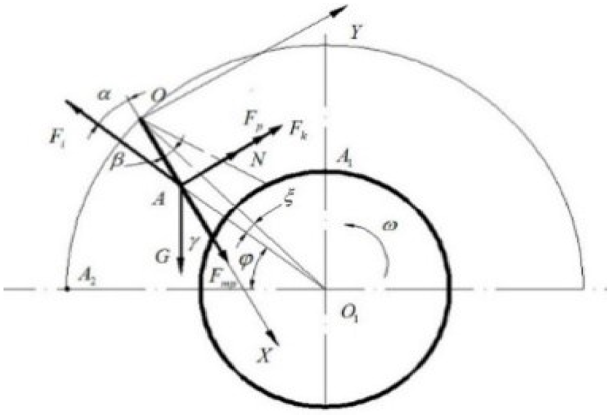


Fig. 5. Calculation scheme for determining the Cutter Tooth profile of the grinding device for bast raw materials

When the rotor tooth rotates, the stem paper M that entered it will rotate with it and move along its surface. At the same time such forces act on the material paper M : the paper gravity ($G = mg$), centrifugal inertia force ($F_i = mR\omega^2$), Coriolis force ($F_\kappa = 2m\omega V_r$), friction force ($F_{mp} = f_{mp} \cdot N$), cutting force F_p. To match the model, only its normal component is taken into account, where R - the rotor radius, ω the angular velocity of the rotor rotation, m - the mass of the material paper, f_{mp} - the coefficient of friction of the stem sliding along the metal.

Let us compose a system of equations for the sum of the projection of forces acting on a paper in the direction perpendicular to the Cutter Tooth surface and the projection of forces on the axis OX and, solving them, we obtain the differential equation of paper motion by the Cutter Tooth surface:

$$\ddot{x} = f_{mp}\left[R\omega^2 \sin\alpha - \frac{F_p}{m} + 2\omega\dot{x} + g\sin\gamma\right] - R\omega^2\cos\alpha + g\cos\gamma \tag{1}$$

The Cutter Tooth profile of the drum will be determined by changing the angle β at the height of the Cutter Tooth. The angle β is the angle between the line passing through the top of the Cutter Tooth p. A. And the center of rotation of the drum p. O_1 and perpendicular to the normal reaction of the Cutter Tooth surface. Determination of angles is carried out in accordance with Fig. 4, and substituting into formula 1, we obtain the final level of motion of the p. A

$$\ddot{x} = f_{mp}\left[R\omega^2\sin\left(\arcsin\frac{x\cdot\sin|\beta|}{\sqrt{x^2+(R+H)^2-2x(R+H)\cos\beta}}+\beta\right)-\frac{F_p}{m}+2\omega\dot{x}+g\sin\left(\frac{\pi}{2}-\varphi-\beta\right)\right]-$$
$$-R\omega^2\cos\left(\arcsin\frac{x\cdot\sin|\beta|}{\sqrt{x^2+(R+H)^2-2x(R+H)\cos\beta}}+\beta\right)+g\cos\left(\frac{\pi}{2}-\varphi-\beta\right) \tag{2}$$

The optimization problem as a design parameter is chosen the angle of the Cutter Tooth profile β , the target function is the path taken by the material paper M during its movement and is described by equation (3), and the constraints are the geometric and kinematic parameters of the mechanism (R , H , ω). That is, the optimization problem is formalized as following:

$$\left.\begin{array}{l}\ddot{x}_i(\tau)\to\max \\ 0\le\varphi\le\dfrac{\pi}{2}\end{array}\right\} \tag{3}$$

Finding a solution to system (9) at each moment of time τ_i means setting such a profile angle β_i value at which $\ddot{x}$ … x . That is, the material paper M will move from the base of the Cutter Tooth to its top in the maximum possible way. This makes it possible to perform the cutting conditions of plant materials as accurately as possible. A numerical experiment was performed by using the mathematical package MathCad. Since the analytical solution of the second-order differential equation (4) causes difficulties, we used numerical isolation schemes, in particular, by using the Runge-Kutta method is a fixed step. While calculating, the following numerical values of the parameters were used: Rotor radius $R = 0.3$ m; Cutter Tooth height $H = 0.1$ m; angular velocity of rotation of the rotor $\omega = 5\ldots$ s^{-1}; coefficient of sliding friction $f_{mp} = 0.2$; normal component of the cutting force $F_p = 40$ H; mass of stem $m = 1\ldots$ g.

The result of the calculations was obtained in the form of graphs (see Fig. 6).

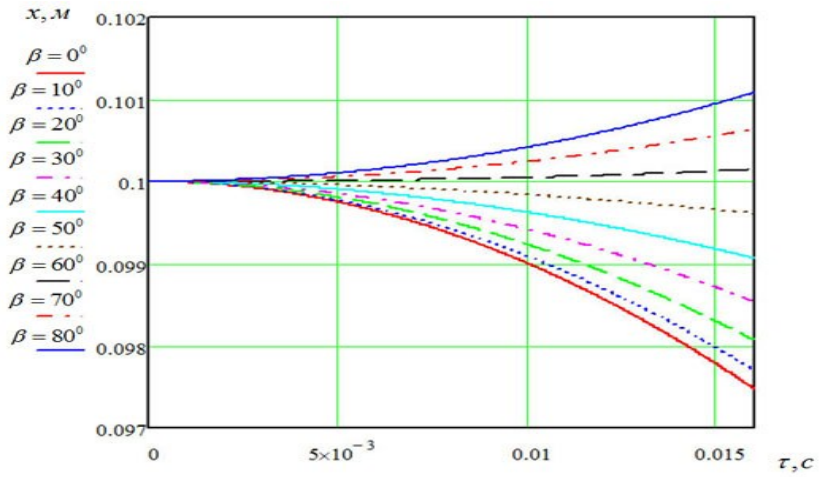
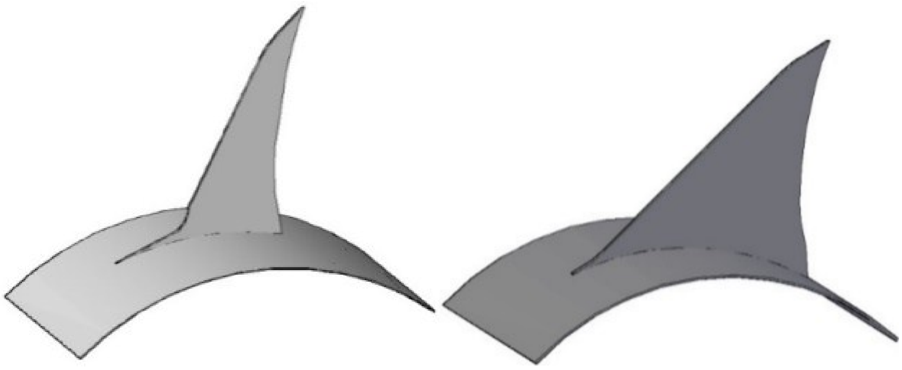


Fig. 6. The change of coordinate x point M with the time

The analysis of the results of the proposed mathematical model of the Cutter Tooth profile showed that the angular velocity of the Rotor wrapping has a significant effect on the profile curvature. At speeds $\omega < 5\,s^{-1}$, a "sticking" of a material paper is observed at the base of the Cutter Tooth and its movement along the cutting surface is not observed. Based on the calculations, the Cutter Tooth grinding mechanism is S-shaped (see Fig. 7). The greatest curvature of the profile is observed at the base and at the top.

Only minor portions of the Cutter Tooth profile have significant curvature. To improve the technology of Cutter Tooth making, use of teeth with a linear profile can be tolerated. It is only necessary to choose the optimal angle of inclination of the Cutter Tooth β. The graphic result of the calculation of the movement point M of the surface of the whole Cutter Tooth is shown in Fig.8.



a) b)

Fig. 7. The calculated profile of the Cutter Tooth: a) $\omega = 20\,s^{-1}$, b) $\omega = 40\,s^{-1}$

According to the calculations, the rational angle of inclination of the Cutter Tooth β is 50°. At this angle, the working surface of the Cutter Tooth should be done with a straight line and not closer to the top at a distance of 40 mm, the working surface should be rounded.

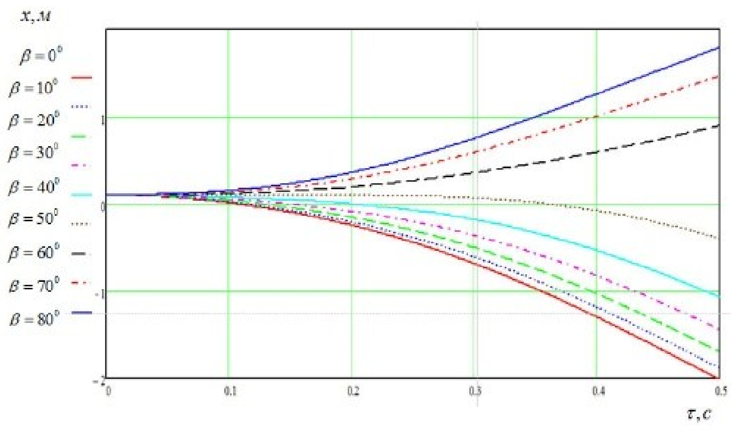


Fig. 8. The choice of the angular of the linear Cutter Tooth profile

Experimental studies have confirmed theoretical calculations to establish the cutting angle of oil flax stems, which is used both in the segment-finger cutting devices and in installations for breaking the stem mass during its gathering and singling out of short unoriented fiber. The analysis of the experimental data obtained indicates that the use of a segmental finger cutting device for the gathering of oilseed flax has an important cutting angle and it should approach 60° in the communal zone. Experiments show that in the full ripeness phase the cutting angle does not affect the applied force. At the same time, the resistance of the cutting of stems in the communal part fluctuates within the limits of 17.0 N, the middle part is 12.5 N, and in the upper part it is 7.7 N. A slight force indicates a considerable jumble of the stem. In this case it is necessary to use a flax puller for the gathering of Oilseed Flax

Thus, the principle of grinding the stem mass of oil flax can be laid in the design of a universal combine. Then it is enough just to destroy the surface part of the stems in the early ripeness phase and, as a result, to obtain a fiber suitable for usage in the textile industry. But at the same time for highlighting the fiber, it is necessary to grind the straw pulp. In the case of the gathering of Oilseed Flax in the phase of full ripeness, when the fiber loses its valuable textile properties, straw can be formed into fuel materials. The papers of awn selected by the proposed device (see Fig. 9) with a length of 3-5 mm can be directed to the production of fuel briquettes, and the fiber of an average length of 30-50 mm for additional treatment with subsequent use in various areas.

a) b)

Fig. 9. The components of the stem part of the Oilseed Flax after grinding by the device: a) awn; b) fiber

CONCLUSIONS

For each natural and climatic condition in crop rotation there must be crops which requires the use of a minimum amount of technology. Oilseed Flax is referred to industrial crops, but the technology for producing products from it is similar to the plants of the grain group. According to the scientific approach, Oilseed Flax is considered to be a culture of waste-free production, but a high stem, which can reach one meter has become an obstacle in the wide distribution of oil flax on the territory of Western Polissya. Therefore, the results presented in the paper indicate the prospect of applying the combined approach when using the stalk of flax oil. The technologies for the production of oil flax in the conditions of Western Polissya are imperfect and need to be modernized with harvesting operations in order to use the full potential of the plant. The main problem that has not been solved to date is the utilization of the stem part of the crop. For utilization of NOT crop seed residues, a method of modeling the means for grinding the stem part of oil flax has been proposed. Further processing of such raw materials is possible through the manufacture of fuel materials.

In accordance with the weather conditions of the current season, it is possible to obtain high-quality non-oriented fiber or cylindrical fuel materials from the stems. For both cases, the destruction of the stems operation is required. Theoretical and experimental studies have been carried out that make it possible to obtain and apply mathematical models in the calculation and design of machines and units required for the proposed technology of cultivating Oilseed Flax.

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Study of rice and maize grains grinding energy

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Summary. The work focuses on the issues connected with grinding, breaking the biomaterials. The aim of this work was to investigate the grinding energy of rice and maize grains. The research problem was formulated as a question: (*1*) how the energy of grinding depend on the materials strength property, (*2*) is the Kick's theory suitable to estimate the grinding energy? To resolve the problem the grinding energy was estimated using Kick's theory and calculating it as work done during static compression test. Based on the tests it was found that the average energy needed to break the grain was higher for corn grains than for rice. For both tested grains the average energy calculated based on Kick's theory was lower than average energy estimated as needed in compression test.

Key words: grinding, biomass, energy, kick's theory

INTRODUCTION

Biomass plays a significant role in energy production sector. Most of organic materials used for solid bio-fuels production need to be specially prepared, for example dried, grinded, compacted and so on [*Rezvani i in. 2013*). Grinding operations are most popular preparation processes in energy biomass processing chain because of the accompanying advantages i.e. material structure size reduction, releasing the substances accumulated inside the material, increasing the specific surface area [*Salman i in. 2007; Johnson, 2006, Eisenlauer i Teipel, 2017*].

Although the obvious advantages, during grinding the significant amount of energy is consumed, which is undesirable phenomenon considering the global trends of reducing energy consumption in industrial sectors. This reasons makes engineers to design new grinding machines characterized by low energy consumption [*Wołosiewicz-Głąb i in. 2017; Wang i Forsberg, 2000*].

In grinding machines design process important role plays designing of grinding unit geometry. Its strongly depends on properties of material to be shredded, especially the strength parameters, also the grinding energy, which is useful in predicting the power of grinding machine [*Feliks i Filipowicz, 2009; Ligaj i Szala 2009*].

The aim of this work is to investigate the grinding energy of rice and maize grains. The research problem formulated as a question: (*1*) how the energy of grinding depend on the materials strength property, (*2*) is the Kick's theory suitable to estimate the grinding energy?

To resolve the problem the grinding energy was estimated using Kick's theory and calculating it as work done during static compression test.

MATERIALS AND METHODS

For the tests two types of grains maize and corn grains were used. This are crops with biggest planation areas, production potential and are very often grinded, especially in food industry. For the research selected 100 maize grains and 100 rice grains and described its geometrical and physical parameters. Its average values for 100 grains were presented in table 1.

Tab. 1. Physical and geometrical parameters of selecetd grains – average values [*own research*]

Parameter	Symb	Unit	Corn grains	Rice grains
Length	a_1	mm	10,65	6,38
Width	a_2	mm	7,85	1,91
Thickness	a_3	mm	4,88	1,51
Density	ρ	g·c	1,2	1,11
Weight	m	g	0,302	0,016
Volume	V	mm	251,17	14,82
Young's	E	MP	74,30	143,66
Compression	R_s	MP	7,90	17,77

Kick's theory, also called volume theory, was developed in 1885 by F. Kick. It's based on knowledge about material strength parameters while its compressing or hitting. It is assumed that the resulting deformation of the material occurs under the influence of the acting external load (compressive force), which gives rise to stress in the material being crushed. At the moment when the stresses generated exceed the value of the compression strength limit, the grain breaks down into smaller fragments, in other words it is fragmented. The work needed to divide (one-time crumble) of a body with a specific shape is equal to the product of body weight and the division work (one-time crumbling) of the unit of its weight (or the product of the body volume and the division of the unit of its volume). For this case, the formula for work according to Kick is presented as follows [*Selenta i Ciężkowski, 2005*]:

$$L_K = L_{jK} \cdot V = \frac{\sigma_N^2 \cdot V}{2E} = C_K \cdot V, \ [J] \tag{1}$$

where:

C_K – material constant [MPa],

L_{jK} – work to divide the volume unit ($L_{jK} = C_K$) [MPa·m^{-3}],

V – volume [m^3],

σN – normal stress [MPa],

E – Young's modulus [MPa].

In the case of static compression, in order to determine the forces and stress, and subsequently the work (energy) needed to crush one grain, and then a dozen or so grains, a static compression test on the Instron 5966 testing machine for the tested rice and maize grains was carried out. In this way energy ranges to destroy the grain structure were determined.

During the compression of the grain, there is a force F that causes it to break (displacement s), so can be determine the elementary work done over the grain by the force F causing the crack:

$$dW = \vec{F} \cdot ds \tag{2}$$

Because during compression we are dealing with a variable force F and the displacement $s \rightarrow 0$, then work can be determined by integrating both sides of the equation:

$$W_1 = \int_{s_1}^{s_2} F ds \tag{3}$$

then the work during compression of one grain is the area under the graph $F = f(s)$ (Fig. 1).

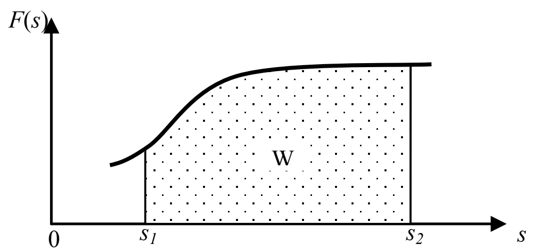

Fig. 1. Graphical representation of the work during grain squeezing [*own work*]

To estimate the energy needed for crushing the grain only partial energy of compression may be taking into account. During compression four phenomena are observed: (1) there is an increase in stresses and, as a consequence, the first crack of grain that does not cause its decomposition, (2) further increase in stress and grain breakdown, (3) further crushing and simultaneous compression of grain fragments, (4) compression of grain fragments (Fig. 2).

The energy required for a single grain division is represented by the sum of fields (1) and (2). The crushing energy is the sum of the fields (1), (2) and (3). In this work estimated energy required for a single grain division and compared it with values of energy calculated on the basis of Kick's theory.

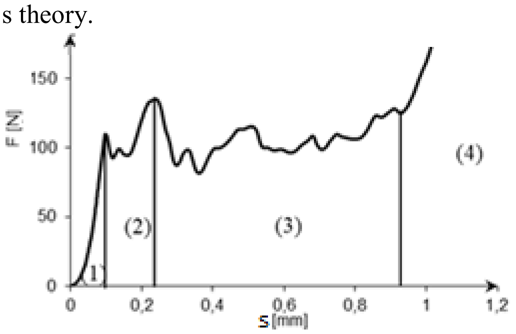

Fig. 2. Interpretation of graph F=f(s) for estimating the energy of single grain division [*own work*]

RESULTS AND DISCUSSION

The results of grinding energy estimated by two methods: as work during compression test W(1)+(2) and on the basis of Kick's theory L_K were shown in table 2. The average energy needed to break the grain was higher for corn grains ($W_{(1)+(2)}$=211.97 mJ, L_K=200.49 mJ) than for rice ($W_{(1)+(2)}$=28.03 mJ, L_K=15.09 mJ). For both tested grains the average energy calculated based on Kick's theory was lower than average energy estimated as needed in compression test (Tab. 2.)

Tab. 2. Values of grinding energy – average for 100 grains [*own research*]

Method	Symbol	Unit	Corn grains	Rice grains
Energy estimated on the basis of compression test results	$W_{(1)+(2)}$	mJ	211.97	28.03
Kick's theory	L_K	mJ	200.49	15.99

If analyzing the grinding, breaking energy for each grain it can be observed that the $W_{(1)+(2)}$ was little bit higher than L_K for most rice (Fig. 3.) and maize (Fig 4) grains. The differences in obtained energy values may occure because of the measurement errors of grain strength and errors of the strength machine. Lower L_K energy values than values of $W_{(1)+(2)}$ may be caused by the assumptions of Kick's theory. In calculation L_K energy was not taking into account the energy dissipation, which occure in real material breaking.

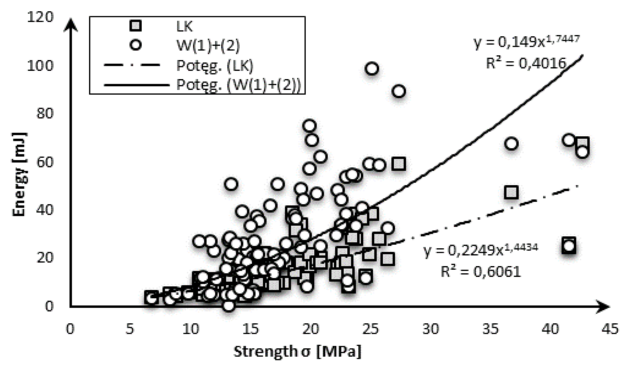

Fig. 3. The energy of grinding in dependence of rice grains strength [own research]

Analyzing how the strength properties of material affects the energy needed to cause the grain breaking it can be said that the correlations are statistically significant (Fig. 3-4). Generally observed that energy was increasing with the material strength inrease.

The approximation functions presented in Fig. 3 and 4 are significant and adequate, because for all approximation curves, p-value <0.0001 and linear correlation coefficients r>0.6 for the presented double logarithm model were obtained. On this basis, using the Guillford scale, it can be concluded that the relationships are moderate and the correlation coefficients r are real. Among the tested other models: linear, exponential, polynomial, logarithmic, the chosen power model and its reduction to the double logarithmic model had the highest values of the correlation coefficient r and the coefficient of determination R^2. The calculated coefficients of determination, despite the value in the range: 0.4-0.61, for 100 tests (large representation) show that the mathematical model describes enough the energy variability. The simultaneous analysis of variance confirms that the constructed regression equations are significant.

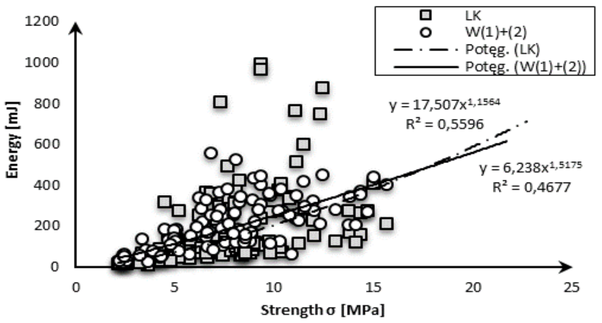

Fig. 4. The energy of grinding in dependence of maize grains strength [own research]

SUMMARY AND CONCLUSIONS

Based on the tests carried out, it was found that: the results of the energy required for the grain crushing calculated on the basis of the strength machine's indications $W_{(1)+(2)}$ and on the basis of Kick's theory L_K are similar; in the case of Kick's theory, the average energy from 100 grains turned out to be lower for both rice and maize; grinding energy depends on grains structure and it's mechanical properties such as strength; as the strength of the grain increases, the energy needed to break it increases.

The Kick's method used for calculations are commonly used to estimate the energy of grinding the biomass grains especially in grinding machines designing process. According to obtained own results and experiment carried out it can be said that Kick's theory is good tool to estimate the grinding energy, but it should be taking into account that this method do not involve the dissipation and losses of energy during ex. cutting, grinding and values of real energy used are higher.

The presented results are important from the point of view of the granular material grinders design, in particular of rice and maize grinders. The determined grinding energy range can be used in the design and selecting the power of the grinders drive units and in the grinding process simulation models (numerical) to optimize the working unit design.

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