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# The modern status analise of working conditions of current industry in the field of transport engineering

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S u m m a r y. In this article the analysis methodology for assessing the severity of conditions in the workplace as an example of current industry in the field of transport engineering, as well as the estimation of conditions for psychophysiological factors in compliance with regulatory requirements.

K e y w o r d s : working conditions, injuries, category of severity of labor productivity, physiological factors.

# INTRODUCTION

In recent years, amid increasing technical equipment and constantly improving the working environment more clearly is the need to consider the impact stress of physiological functions in the workplace as an important factor that determines the able to work and health. As overstrain individual organs and systems, and its failure adversely reflects on the body condition and reduce the efficiency of labor, physical component which is still significant specific weight in engineering [13, 15, 20, 21, 23].

A state policy in the sphere of a labour protection and new safety concepts and nonaccident rate productions on industrial activity objects provide first of all an objective estimation of dangers and allow to plan ways of effort to combat them. In this connection increasing value gets exploring and designing interrelations in system "person-machineenvironment" that has created necessary preconditions for perfection of existing norms and requirements to the workplace organization, and has caused occurrence of new research problems.

Nowadays widespread opinion that the accidental majority (80%) is caused by human mistakes or the behaviour contradicting safety precautions. According to the benor of coordinated opinion often expressed by supervising employees that the reason of accidents is "imprudence" or "levity". The victim in accident, on the contrary, gires as the reason "time trouble", "race", "cares" or "nervousness". These opinions are needed to oppose the fact that even at high degree of rationalization in actions for a labour protection it is impossible to do without requirements to safe workers behaviour which often are not carried out. The "unwillingness" and "inability" are difficult to distinguish among themselves; but both unwillingness inability can have the ergonomic reasons. Labour protection experts should include similar aspects in the menacing dangers

analysis and working out actions for accident prevention.

Every year in the world, according to information of IOW, approximately 270 million accidents, related to implementation professional duties. and 160 million professional diseases are registered. Almost 354 thousands of workers perish on a production, from them in countries with the developed market economy -16,2 thousands, in former social countries - 21,4 thousands, in China - 73,6 thousands, in Indium - 48,2 thousands, in other countries of Asia and Pacific ocean - 83 thousands, in countries Near east -28 thousands, in the countries of Africa in the south of Sahara -54,7 thousands, in the countries of Latin America and Caribbean pool 28.6 thousands. \_ Unfortunately, about 12 thousand of died children. It is also necessary to take into account the amount of workers which got professional disease and were excluded from a production process, for example, in 2004 2,2 million persons are incorporated, thus 32% the oncologic made, 23% - warmly vascular, 19% - traumatology, 17% are infectious diseases. As a result of illness every day in the world is absence on the workplace about 5% labour force. Through charges, related to the industrial accidents, lost to 1250 milliards dollars, or about 4% of world gross domestic product.

Professional activity of workers of many branches of industry remains dangerous, without regard to technical progress, as related to mobilization of functional backlogs, and in many cases passes in extreme and emergency situations, that requires enhanceable physical and emotional firmness. Exactly such workers which are added an enhanceable risk for a health require the special attention from the side of the state. Ukraine for the amounts of mortal accidents on 1000 workers substantially (negatively), as an analysis of the state of industrial safety testifies, exudes between the economic developed countries and former socialistic countries of Europe (Ukraine -0,104, countries with a market economy -0,038, former socialistic countries of Europe -0,053). According to [2] Ukraine occupies the

second after Portugal on a traumatism and 20 place after China for deaths of people on a production.

Most failures happen through fault of factor. Results of analysis of human production traumatism and death rate from industrial accidents in Ukraine confirm, that reason of plenty of accidents are mistakes of workers, through what every year injured to 75% and all of about 80% victims perished, group accidents also took a place through fault of «human factor» - 75-85% (after statistical materials of Ukrainian State mountain industrial supervision bulletins).

Ability to obtain "human operator" occupational injury depends on the workplace conditions that characterize the intensity and severity of labor, pszchophysiological characteristics and employee communication a number of specific factors. Analysis of the impact of both harmful and dangerous production factors (HDPF), and the qualities and capabilities of the human operator in real dynamics of production is a complex engineering task.

# MATERIALS AND METHODS

In connection with an economical situation which was folded in Ukraine, the brightly expressed forms of chronic diseases and disability which comes as a result of the ill-timed measures use are all more frequent registered, thus among the persons of young capable working age. Transformation, which is observed in character, flowing and terms of professional diseases development related to diminishing of technological actions intensity, increase of psychoemotional tension level and decline the physical loadings. In same queue, pattern of production modern change, unwillingness of employers instrumental in the exposure of professional diseases on the their development early stages, for avoidance of additional charges on treatment and rehabilitation of a victim, incuriosity of workers in the exposure of professional diseases through possibilities to lost a job is reasons of low exposure and registration of professional diseases.

As a rule, an accident rate and traumatism through fault of «human factor» is conditioned: by insufficient motivation of observance of safety; by the low level of professional preparation on questions of workers safety; admitting to implementation risky jobs of people with the enhanceable traumatism risk, psychophysiological qualities of which do not answer the requirements of certain labour activity; by the presence of factors which reduce reliability and safety of worker activity (fatigue, exhaustion, excitation et ctr.).

As practice shows, in Ukraine of expense on measures in relation to a labour and prophylaxis of accident rate and production traumatism protection in once or twice below than financial losses from failures. In spite of that during realization of any measures it is necessary to take into account financial charges, much major to spare the special attention the social consequences of failures and catastrophes - loss of health, life of citizens and country labour potential, increase of incomplete families amount and childrenorphans. Combination of ecological and professional psychological factors with overloads, from data of WOH, is reason of Approximately most diseases. 30-50% workers of the developed countries grumble about stress overloads to the parahypnosiss, depression, cardiovascular pathology.

Analysis and research of practical results which are conducted in the different countries of the world, show a dependences of the state of health and capacity of workers on their psychophysiological qualities high degree, that testifies about expedience on enterprises with the enhanceable level of production danger psychophysiological selection and psychophysiological examination. Such approach, as developed countries experience testifies, results to diminishing of the technical systems depending on appearance and terms of activity accident rate level on 40-70%, diminishing of technogenic catastrophes amount - on 20-25%, decline of traumatism level as a result of «human factor» - on 40-45%.

Presently conventional in the classification of causes of industrial accidents highlighted three basic types of these reasons [1, 5, 11, 12, 19]. First, a technical reason, which can be described as being dependent on imperfect production processes and the use of physically and obsolete equipment. Secondly, this organizational reasons entirely determined by the level of the workplace and the company as a whole organization. Thirdly, it's personal (psychophysiological) causes, which can be roughly classified physical and neuropsychiatric worker overload, leading to its erroneous actions through mental strain, strain analyzers (visual, auditory, tactile), monotony of work, stress, disease state of fatigue caused more physical (static and dynamic) loads. Injury may lead to discrepancy anatomical and physiological and psychological peculiarities human body of work performed by it. Also in many technical systems, design of machines, devices and control systems have not taken into account physiological characteristics and possibilities of man yet.

Almost all accidents are caused by multiple factors and "accidental" coincidence of events, but first of all violations of safety requirements admitted workers and employers. Considered, that in modern manufacturing all less skilled worker can get into unexpected situations with the "unknown" security requirements, but increasingly openly violated safety rules or unreasonable behavior creates a dangerous situation. In today's difficult for workers of manufacturing joint action to secure individually for its parameters, factors in certain circumstances lead may to dangerous, critical or emergency situations, and link this combination is usually workers, which affect the behavior and working conditions.

The analysis shows that in recent years have increasingly come to the fore issues of psychological and physiological voltage employee moving the background need to improve the traditional conditions of work related to exposure to physical environmental factors (temperature, humidity, light, noise, vibration and polluted atmosphere) [3, 6, 7, 16, 18]. This is caused by a relative decrease in physical activity on a person at the same time the growth of psychological and physiological stress. The result is known – chronic fatigue, mental and psychological overload, worsening relations with other workers and management. At the same physiological and psychological fatigue is accompanied by deterioration performance, disease , loss of concentration and coordination, loss of care and diligence. All this substantially increases the risk of injury in the same physical conditions of the workplace.

The aim is to analyze the methodology for assessing the severity of conditions in the workplace for example working production in the field of transport engineering and rating conditions for psychophysiological factors in accordance with regulatory requirements.

# **RESULTS, DISCUSSION**

For different types of work are different assessment of their condition. Severity of physical activity can be estimated by the load, which are human muscle have. But the rate of "various weight work should consider qualities" influence of all elements of working conditions in various forms of activity. However, with the same severity on changes in the body of workers can be caused by various reasons. In some cases, these can be HDPF, others – excessive exercise, in the third – lack of movement, etc., it is also possible different combinations of these reasons. Weight of work should to characterize the severity of the cumulative effect of all the elements that make up the human conditions, its performance, health, livelihoods and recovery workers. In this interpretation of the concept of gravity works equally applicable for both mental and the physical labor.

An objective assessment of the severity of work can be done by assessing reactions and changes in the human body, that is based on its functional state. There are three functional states of man: normal, marginal (between normality and pathology) and pathological. They can recognize by medicalphysiological and technical-economic indicators. According to the above established six categories of work conditions. Category severity of labor based on an integrated assessment of biologically significant factors operating conditions. Under biologically meaningful understanding factors such work, which most likely influence the formation of certain reactions (normal, marginal, pathological) body worker. Each biologically significant factor estimate in points from 1 to 6. Category severity of labor is determined by the following data [8, 9, 10, 22, 17]:

> I category – 18 points, II category – 19,7-33,0 points, III category – 34,4-45,0 points, IV category – 45,7-53,0 points, V category – 53,9-58,5 points, VI category – 58,9-60,0 points. Based on the basic theoretical concepts

and using job evaluation data on the effect of plant below shows the general characteristics of jobs manufacturing facilities by major environmental factors.

In areas of the enterprise departments exist or may arise in the implementation process of the processes following physical factors:

- moving machines and mechanisms,

- moving parts production equipment and products,

- high or low temperature,

- excessive dust and air pollution,

- high or low humidity,

- insufficient illumination of the workplace,

- noise and vibration in excess that allowable standards,

- high levels of electromagnetic fields,

- high level of static electricity,

- risk of electric shock.

Harmful psychological factors that influence employees during the work shift can carry on physical and neuro-emotional (static and dynamic) congestion, work monotony, mental stress, strain analyzers.

In Table. 1 the determination of harmful and dangerous physiological factors for severity of labor for the results of job evaluation, in terms of which there is a surplus of norms.

		No	Mo		Severity	of labor				
№	Shop,	JN≌	JN≌	Dyna	mic.	Sta	tic.	Working out		
п/п	position, profession		similarly.	wo	rk	wo	ork		-	
	1 /1	place	place	stand. fact		stand.	fact	fact stand.		
1	2	3	4	5	6	7	8	9	10	
1		5	•	e	v	,	0	,	10	
12	duber	4	5.59					>50%	59 40%	
1.2	molder hand forming	20	5,54	> 20.5	18.8			2070	57,1070	
2		20		>30,5	40,0					
						12001				
2.5	gas welder	8-20				43000	42750	25%	43,70%	
2.6	plumber	6-22;6-26; 6-28;6-41; 7-11;7-12	6-38;6-39;6-42; 6-50;6-51;6-52			18001- 43000	61560	25%	47,90%	
2.8	metalizater	101				18001- 43000	48300	25%	41,60%	
2.9	metal cleaner	99				43001- 97000	174600			
2.16	painter	6-10	100			18001- 43000	51300			
3	MST									
3.1	batterier	1	4	37-63	67			25%	47,90%	
3.2	copper	68	3;67;69;;71			18001- 43000	43500	25%	33%	
33	electronlating	10	3.0.15	18-30.5	39.48	15000				
5.5	electroplating	10	5,7,15	10-50,5	57,40	18001-				
3.5	electric gas welder	39	38			43000	40800	25%	48%	
3.9	hydro sand pourer	20	17;;19	23-45	72,8	43001- 97000	70632			
3.10	heat-treaters	15;25;,26	29;;31;33	41-90	112,5					
3.11	painter	1				18001- 43000	91134	25%	67,70%	
3.13	polisher	4-18	4-17;4-19					25%	45%	
3.16	electric welder	48-1	48-2			18001- 43000	44544	25%	48%	
3.18	exile	2-11	2-2;2-3; 2-17;2-21					25%	48%	
3.19	bath adjuster	15	12;;14	37-63	65,25					
4	IST									
4.3	batterier	1	2:5	23-45	47,1			25%	35,43%	
4.5	mechanic mechanical	1	7;;10		.,			26-50%	47,83%	
4.6	driver vtutrishnoho	1	7;;10					26-50%	41,35	
5									-	
3						10001				
5.7	electric welder	90-1	90-7			43000	49680	>50%	37,50%	
5.10	painter	100-1	100-3;100-4			18001- 43000	58760	>50%	51,50%	
5.11	cutter	8-1;3				18001- 43000	72000			
5.12	hand forged blacksmith	301-3	301-4			18001- 43000	69600			
5.13	smith - stamper	301-1	301-2	23-45	72,2					
6	TRT									
6.1	electric gas welder					18001- 43000	24000	25%	41,60%	
6.2	electric welder	1-34	1-32;1-33			18001- 43000	25500	25%	39,50%	
6.7	painter	1-5.1	1-5.2;;5.4; 2-62;2-59;2-60; 3-5.1;;5.8			18001- 43000	49800	30-50%	41,60%	

 Table 1. Comparative evaluation of the actual conditions in the workplace in mechanical engineering from the regulatory requirements for psychophysiological factors

1	2	3	4	5	6	7	8	9	10
6.8	metal cleaner	Пр3-15				43001- 97000	125400		
6.9	hand forged blacksmith	2-91.1;2-90	2-91.2	23-45	54,85				
6.11	electric welder on automatic and semiautomatic machines	4-15к-19к				18001- 43000	24000	25%	38,50%
6.12	roller in	4-19к-20-к				43001- 97000	105300		
7	RMT								
7.1	heat-treater	108		23-45	49	42001			
7.2	roller in	135				43001- 97000	45840	25%	37%
8	PKT "Tool Manufacture"								
8.1	electric welder	12	13;13-1;;3			18001- 43000	40800	25%	46,00%
8.5	smither	2-5				43001- 97000	151200		
8.7	electric gas welder	14				18001- 43000	40800	25%	45%
9	TOE								
9.1	locksmith	21	22;;27			10001		25%	55,20%
9.2	electric gas welder	28				43000	45750		
10	TZP	1		10.20.5	22.52				
10.1	bakeliter	1		18-30,5	33,33	43001-			
10.2	polisher	71				97000	100320		
10.3	electroplater	3	4-10	18-30,5	37,77				
11.1	A I I batterier	301		23-45	70.78			25%	38.50%
12	TST				,				
12.1	painter	8-27	8-28;;30			18001- 43000	85905	25%	23,96%
12.2	etcher	8-22	8-17;8-18	18-30,5	38,28				
13	RT								
13.2	electric welder	291	292			18001- 43000	40800	25%	46%
13.6	electric gas welder	212	211			18001- 43000	40800	25%	48,00%
13.7	polisher	133						25%	44,80%
13.8	painter	490				18001- 43000	79680		
13.9	roller in	344	345					25%	45,80%
14	ТОМ					10001			
14.1	roller in	6-3	6-4;;6-6;6-8; 6-11			18001- 43000	45750		
14.2	gascutter	4-1	4-2			18001- 43000	40200	25%	47,90%
14.3	painter	1	2;3			18001- 43000	58515		
14.9	electric welder	по цеху				18001- 43000	39000	25%	45,80%
15	IPT "Pamir"				60.55			<b>a -</b> 0 :	00.000
15.1	pressed-vulcanizer	1	2-6	37-63	69,12			25%	39,50%
15.2	former	12	13-16					25%	41,60%
16	Typography			20001					
16.1	sealer manually	10	11;13	40000	50000			25%	47,90%
16.2	sealer	16	17;18	20001- 40000	42500				

The analysis of working conditions in the workplace in current production (Table 1) showed that physical activity (dynamic and static) and time that spent in an uncomfortable working position significantly exceed regulatory requirements, such as electric welder jobs, gas welder jobs, painters, batteriers and others, so it is necessary to assess the severity of labor for the calculation of compensation and benefits to employees and further develop measures to eliminate deviations.

Methods of assessing the severity of work establishes the relationship between working conditions and the integrated response of the human body. It takes into sanitaryhygienic account and psychophysiological requirements for working conditions. The former include the presence in the work area exceeding standard indicators of microclimate (temperature, humidity and air velocity, toxic substances, dust, vibration, ultrasonics, heat noise, the radiation, electromagnetic fields, biological factors, etc.) [2, 24, 25, 26].

In the latter include:

- physical, dynamic and static load,

- worker working pose and his movement in the work area during the period of the working time,

- variability and duration of continuous operation per day,

- the accuracy of visual works,

- number of observation given objects,

- pace of work, its monotony,

- the amount of information received and processed,

- the mode of work and rest,

- neuro-emotional and intellectual activity.

In assessing the severity of labor into account the elements of working conditions that actually affect the employee's particular job. In this case, each element receives a quantitative assessment criteria on a scale from 1 to 6 (Table 2).

With the simultaneous influence of several factors integral assessment of severity of labor in points determined by [2]:

$$U_{T} = \left[ X_{\max} + \frac{\sum_{i=1}^{n} X_{i}}{n-1} \cdot \frac{6 - X_{\max}}{6} \right] \cdot 10, \quad (1)$$

where:  $U_T$  – integral factor in the difficulty category scores,

 $X_{max}$  – element of working conditions in the workplace that has the highest score,

 $\sum_{i=1}^{n} X_{i}$  – quantify the amount of points important elements of working conditions without  $X_{max}$ ,

n – number of elements working conditions,

10 –number that entered for ease of calculation.

According to the value of the integral indicator of working conditions, work performed, is assigned to one or another category of severity (Table 2).

Table 2. Dependence severity categories of labor fromintegrated assessment of working conditions [14]

Category of labor	1	2	3	4	5	6
Integrated assessment of working conditions, U <sub>T</sub> , points	till 18	18,1-33	33,1-45	45,1-53	53,1-59	59,1-60

Category severity of labor indicates the degree of adverse effects of this work on the human body, and therefore to reduce its efficiency. Proceeding of gravity, provided economic recommendations of differentiation payment for working conditions, size of the compensation provided under adverse conditions. Description of existing with harmful and dangerous production factors allows developing action for their elimination and recovery conditions.

When differentiation payment in accordance with the conditions specified items assessing their over-corrected depending on the duration of their impact on the employee during the work shift:

$$X_{i} = X_{i} \cdot \frac{t}{t_{sm}}, \qquad (2)$$

where:  $X_i$  – evaluation of the i-th element of working conditions in points,

t - the actual duration of the initial element of working conditions, min.,

 $t_{sm}$  – time changes, min.

The integral indicator of severity of work determine the impact of working conditions on human performance. For this first calculated the degree of fatigue in arbitrary units. The relationship between the integral indicator of severity of labor and fatigue is expressed b [4] equation:

$$Y = \frac{U_T - 15,6}{0,64},$$
 (3)

where: Y - an indicator of fatigue in arbitrary (relative) units,

15,6 and 0,64 – regression coefficients,

 $U_{\rm T}$  – integral indicator of the severity categories of labor in points.

Knowing the degree of fatigue, it is possible to determine the level of efficiency, the value of opposite fatigue, according to the equation:

$$R = 100 - Y$$
, (4)

where: R – the level of efficiency in relative units.

Accordingly, we can estimate how performance changed with a decrease or increase in hard of work and how it affected her performance:

$$P_{\rm PT} = \left(\frac{R_2}{R_1} - 1\right) \cdot 100 \cdot 0, 2, \qquad (5)$$

where:  $P_{PT}$  – increase productivity,

 $R_1$  and  $R_2$  – performance in conventional units before and after the introduction of measures to reduce hard of labor,

0,2 – correction factor that reflects the average correlation between the increase of performance and increase productivity.

In addition, integrated assessment of working conditions can predict injuries in the enterprise. Growth of industrial accidents on automated lines defined by the expression:

$$K = \frac{1}{1,3 - 0,0185 \cdot U_{\rm T}},\tag{6}$$

where: K – the growth of industrial accidents, the number of times,

 $U_{\rm T}$  – integral indicator of the severity categories of labor in points.

The design and manufacturing process equipment provides an optimal working environment and to achieve conditions that correspond to the first category of weight work.

If the equipment is perfection structural developments involving not only performance, but also with anticipation rigging equipment safety devices, etc., the value of production traumatism taken as a 1 unit, and in this case, the integral indicator of the severity of labor equals:  $U_T = (1,3-1,0) / 0,0185 = 16,2$ , describing the project trauma danger production process. When improving conditions (decrease the integrated assessment elements conditions under 16,2 points) going on reducing injuries growth and the deterioration - increasing or increased injuries on the project trauma danger project.

## CONCLUSIONS

1. The investigation revealed deficiencies of existing methodologies to assess the severity categories of labor, including those related to working posture of the human operator.

2. During assess the severity categories of labor does not count amplitude and direction of limb movements, and load them in the workplace.

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#### АНАЛИЗ СОВРЕМЕННОГО СОСТОЯНИЯ УСЛОВИЙ ТРУДА НА ДЕЙСТВУЮЩЕМ ПРОИЗВОДСТВЕ В ОТРАСЛИ МАШИНОСТРОЕНИЯ

#### Андрианова Александра, Анисимова Тамара

В Аннотация. статье проведен анализ методологии оценки категории тяжести труда рабочих мест на примере действующего производства в машиностроительной отрасли, в частности, по тем факторам, которые касаются психофизиологической нагрузки, в соответствии с действующим законодательством.

Ключевые слова: рабочие места, травматизм, категория тяжести и производительности труда, психофизиологические факторы.

# Wind regime on the waste dumps

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S u m m a r y. The articles describes the wind regime on waste dumps. The performance of Donbass wind regime and possibility of their maximum use in terms of WPP installation on the surface of coal mines waste dumps were investigate.

K e y words: wind energy, coal mines waste dumps, wind regime.

#### **INTRODUCTION**

Wind energy is one of the alternative [12-15]. While in Western Europe this type of energy is extensively used and wind power plants (WPP) are the active suppliers of electricity, in Ukraine this kind of energy is just being developed [1-4]. One of the most windy regions of Ukraine is Donbass, but using of wind energy is accentuated by high relief and lack of space to accommodate a power plant [5-7, wind 11]. These disadvantages can be compensated by using the surface of coal mines waste dumps [8-10, 16, 17].

However, based on a special shape of these objects, study of the wind regime which is mandatory to locate the WPP on their surface, is problematic [18-20, 23].

The aim of this work is to study the wind regime on waste piles. To achieve this goal the following problem was solved: to investigate the performance of Donbass wind regime and possibility of their maximum use in terms of WPP installation on the surface of coal mines waste dumps.

# **OBJECTS AND PROBLEMS**

To solve this problem on a typical for Donbass example of Luhansk region, the factors of wind regime were analyzed. After all, to use the wind turbines on the waste dumps the frequency analysis of winds of different directions is required [21, 22]. According to the detailed wind diagram based upon long-term average annual data for Luhansk region (Fig. 1), the prevailing wind is easterly.

Since Donbass is characterized by rugged terrain, the waste dumps are most commonly located on the braced slopes of different aspects.

To estimate the "advantages" of the location of each waste dump we have proposed and designed the factor varying from 1 to 5 points (according to quality increase). When the coincidence of the dominant points of the compass directions



Fig. 1. Long-term average annual detailed wind diagram of Luhansk region



Fig. 2. Geomorphological analysis of site location dumps on satellite images (Lugansk region, a sample of 42 pieces)

At conjunction of bearings of the prevailing wind direction and exposure of slope, bearing the waste heap, which takes place on the windward slopes, the location of the waste dump is estimated at 5 points. When the exact opposite points of the compass location estimated at 1 point. At complete antithesis of bearings, the location of the waste dump is estimated at 3 points. 2 points is the estimation of the situation, when the angle between exposure bearing and wind direction is  $135^{\circ}$ . If the angle is  $45^{\circ}$  – it is estimated at 2 points, if  $135^{\circ}$  – 4 points.

We have studied the location of 42 waste dumps of Luhansk region (Fig. 2, Table 1).

Prevailing wind,	Bearing of	g of Slope exposure directions		Ball	Quantity of waste dumps		
bearings	apparent wind	alternative	uncetions		pcs	%	
Е	W	W	0°	1	20	47,62	
Е	W	SW, NW	45°, 45°	2	3	7,14	
E	W	S, N	90°, 90°	3	9	21,43	
E	W	SE,NE	135°, 135°	4	4	9,52	
Е	W	Е	180°	5	6	14,29	

Table 1. Evaluating of efficiency of the waste dumps location on the slopes



Fig. 3. Satellite imagery separate heaps of Luhansk region

Table 1 shows the distribution of the surveyed waste dumps over proposed scale.

The obtained results allow to choose waste dumps to place wind turbines on their tops more carefully.

Since the energy of the wind current is equal to half the product of the air density by the reference area of the standard wind wheel and weighted average windspeed raised to the third power, to determine it it's necessary to know the wind speed in a certain area. We analyzed the average wind speed in Lugansk region from 2005 to 2008 (Fig. 4).

We carried out detailing of the wind potential power (to construct WPS on the tops of the waste dumps) by taking into account changes in wind speed at different heights of Donbass coal mines waste dumps.

Were initially analyzed height of 42 coal mines waste dumps of Lugansk region above sea level (Table 2).



Fig. 4. Wind speed in Lugansk region

**Table 2.** Data check: disposition uniformity of 42 waste dumps

n	42	41
$\overline{X}$	233,048	237,195
S	73,2543	68,991
X <sub>max</sub>	351	
$t_{cp} = \frac{X_{\max} - \overline{X}}{S}$	1,61	
$t_{\kappa p}(\alpha, \nu)$	2,00	
Derivation	$H_0$	
X <sub>min</sub>	63	110
$t_{cp} = \frac{\overline{X - X_{\min}}}{S}$	2,32	1,844
$t_{\kappa p}(\alpha, \nu)$	2,00	2,00
Derivation	$H_1$	$H_0$

The obtained altitude above sea level data were checked for uniformity and authenticity. The Table below summarizes the test results of uniformity and authenticity of the altitude above sea level.

To confirm the authenticity of data on 42 waste dumps height above the sea level, a histogram and a polygon have been built (Fig.5).



Fig. 5. The histogram and polygon of distribution in altitude0020of 42 waste dumps of Lugansk region above sea level

п	414,0	413,0	412,0	411,0	410,0	409,0	403,0	396,0	390,0	381,0	378,0
$\overline{X}$	48,7	48,2	48,0	47,9	47,7	47,6	46,8	45,9	45,3	44,4	44,1
S	24,7	22,4	22,1	21,8	21,7	21,5	20,7	19,9	19,3	18,6	18,4
X <sub>max</sub>	260,0	124,3	117,0	111,0	104,0	103,0	96,0	89,0	86,0	81,0	80,0
$t_{cp} = \frac{X_{\max} - \overline{X}}{S}$	8,57	3,40	3,12	2,89	2,6	2,57	2,38	2,16	2,11	1,97	1,95
$t_{\kappa p}(\alpha, \nu)$	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96
Derivation	$H_1$	$H_0$									
X <sub>min</sub>	2	2	2	2	2	2	2	2	2	2	2
$t_{cp} = \frac{\overline{X - X_{\min}}}{S}$	-1,89	-2,07	-2,08	-2,09	-2,11	-2,12	-2,17	-2,21	-2,24	-2,28	-2,29
$t_{\kappa p}(\alpha, \nu)$	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96
Derivation	$H_0$										

Table 3. Check of the heights uniformity of the conical waste dumps of Donetsk region

Further study was dedicated to the dumps height (without regard to their location above sea level). The analysed data below show the heights of the following objects: 210 flat and 100 conical waste dumps of Lugansk region, 414 conical and 182 flat waste dumps of Donetsk region.

All the data were checked for uniformity and authenticity. The following table shows an

example of checking the heights uniformity of the largest group - the conical waste dumps of Donetsk region.

The Figure 6 below shows the confidence test data on coal mines waste dumps obtained by using the rectified chart method.



**Fig. 6.** Confidence test data obtained by using the rectified chart method: a - flat waste dumps of Lugansk region, b - conical waste dumps of Lugansk region, c - conical waste dumps of Donetsk region, d - flat waste dumps of Donetsk region.

The figure shows the obtained probability curves of height of the conical and flat waste dumps of Donetsk and Lugansk regions.

The conical and flat waste dumps of Donetsk and Lugansk regions were compared at first in pairs using Fisher-Snedecor test:

$$F = \frac{S_x^2}{S_y^2},\tag{1}$$

$$t = \frac{\left| \overline{x} - \overline{y} \right|}{\sqrt{\frac{S_x^2(n-1) + S_y^2(m-1)}{n+m-2} \left(\frac{1}{n} + \frac{1}{m}\right)}}.$$
 (2)

And then in block (using Kruskal–Wallis one-way analysis of variance:

$$Q = \frac{12}{N(N+1)} \sum_{\gamma=1}^{a} \frac{1}{n_{\gamma}} \left[ \sum_{i \in S_{\gamma}} R_{i} \right]^{2} - 3(N+1). \quad (3)$$

In each case, the heights of the waste dumps were found to be nonuniform.

Then the coal mines waste dumps of Donetsk and Lugansk regions were zoned according to height and therefore, according to their wind potential power.

To zone them, all the conic and flat waste dumps of Donetsk and Lugansk regions were checked for information content, pursuant to the procedure.



**Fig. 7.** Probability curves of height of the conical and flat waste dumps of Donetsk and Lugansk regions: a - flat waste dumps of Lugansk region, b - conical waste dumps of Lugansk region, c - conical waste dumps of Donetsk region, d - flat waste dumps of Donetsk region.

# Determination of information coefficient and pooled results are shown in the Table below.

	Selection scope			Average value			Actual		Condition of data	
Waste dumps dislocation (region)	$\begin{array}{c c} \text{lumps} \\ \text{ation} \\ \text{on} \end{array} \begin{array}{c} 1^{\text{st}} \text{ sub-} \\ \text{matrix,} \\ n_1 \\ n_2 \end{array} \begin{array}{c} 2^{nd} \text{ sub-} \\ n_1 \\ n_2 \end{array}$		Total, <i>n</i>	$1^{\text{st}}$ sub- matrix, $\overline{X}_1$	$2^{nd}$ sub- matrix, $\overline{X}_2$	Dispersion, $S_2$	value of the information coefficient, $V^2$	Tabulated value, $\chi^2$	informative: $V^2 \ge \chi^2$ informative, $V^2 < \chi^2$ not informative	
Lugansk region (flat waste dumps)	46,0	46,0	92,0	42,57	47,47	198,27	2,76	3,8	Informative	
Lugansk region (conic waste dumps)	103,0	103,0	206,0	60,33	52,65	549,11	5,67	3,8	Informative	
Donetsk region (flat waste dumps)	82,0	82,0	164,0	35,64	29,66	273,87	5,33	3,8	Informative	
Donetsk region (conic waste dumps)	189,0	189,0	378,0	45,33	42,85	337,12	1,89	3,8	not informative	

Table 4. Determination of information coefficient using the waste dumps height

#### CONCLUSIONS

1. Heights 42 heaps of coal mines are investigated. All of them are in the Lugansk region above sea level. Results checked for uniformity and accuracy.

2. Results obtained by evaluating the effectiveness of the location on the slopes of the heaps of wind turbines. They allow more true dumps choose to be placed on top of their wind turbines.

3. Obtained expression for the energy of the wind potential for the changes in wind speed at different heights heaps of coal mines in the Donbas.

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#### ВЕТРОВОЙ РЕЖИМ НА ТЕРРИКОНАХ

#### Валерий Буняченко

Аннотация. В работе проведено изучение ветрового режима на терриконах. Исследованы показатели ветрового режима Донбасса и возможности максимального их использования при установке ВЭС на отвалах угольных шахт.

Ключевые слова: ветроэнергетика, породный отвал, ветровой режим.

# Pressue losses design while bulk solids pneumatic conveying

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S u m m a r y. A new theoretically justified technique of the hydraulic design of aerodispersed flows in horizontal pipes is developed. The existing techniques are of empiric nature and are correct only for a limited range of conditions that are close to the experiment conditions. The new technique is developed on the basis of the solution of the Bernulli's equation for two phase flows considering the latest researches in the sphere of hydraulic conveying.

The revised designs by the new technique show their conformity to the results of the experimental researches within the wide range of characteristics of pneumatic conveying systems and conveyed materials.

K e y w o r d s : pneumatic conveying, aerodispersed flow, hydraulic design, bulk solids

# **INTRODUCTION**

Under the conditions of the increasing use of pneumatic conveying systems in the different fields of industry there arises the further necessity of researches of aerodispersed flows. Problems of engineering and using of pneumatic conveying systems are solved mostly by conducting labor-intensive and expensive experiments. At that, the obtained dependences as a rule are applicable for the limited range of systems, meeting the experiment conditions. The generalization of results of other experimental researches conducted under different conditions leads to considerable design errors. The designs are

conducted with unreasonably high margins. The compressed air overconsumption and its pressure lead to the increase of power intensity of units, primary equipment wear. It makes the air cleaning process complicated and leads to the conveying pipeline falling.

# RESEARCH AND PUBLICATIONS ANALYSIS

The most important task of the bulk solids pneumatic conveying hydraulic design is the correct evaluation of pressure losses along the pipeline that enable the least power consumption at steady conveying process with the specified efficiency.

The well known techniques of the pressure losses hydraulic design can be divided into two types, differing in the main formulas structure. The Gastershtadt formula can be referred to the first type. The formula takes the form [12]:

$$\frac{\Delta P}{L} = (1 + K\mu) \frac{\Delta P_a}{L}, \qquad (1)$$

where:  $\Delta P$  and  $\Delta P_a$  – pressure losses at the pipeline segment of the L length,

 $\mu$  – mixture mass concentration,

K – Gastershtadt empirical coefficient.

As different researchers say the dependence (1) can be considered as general and the numerical values of the coefficient K should be experimentally determined for every individual case.

Upon carefully conducted experiments formula (1) provides the results that are sufficient for engineering practice. It is simple and convenient for engineering designs yet all practical attempts for K coefficient justification have been unsuccessful.

The techniques of hydraulic design, having the Darcy – Weisbach formula for homogeneous liquids as their base (second type) are widely used in the practice of pneumatic conveying systems engineering. One of the variants of this formula suggested by G. Zegler [Zegler 1937] is as follows:

$$\frac{\Delta P}{L} = \lambda_m \frac{\rho_a U_a}{2D}, \qquad (2)$$

where:  $\lambda_m$  – coefficient of hydraulic resistance to the motion of the air and conveyed material mixture,

 $\rho_a$  and  $U_a$  – density and air motion velocity, D – pipeline diameter.

The coefficient  $\lambda_m$  in formula (2) is determined experimentally. The modified variant of formula (2) suggested by V. Bart [Bart 1960]:

$$\frac{\Delta P}{L} = (\lambda_a + \mu \lambda_s) \frac{\rho_a U_a^2}{2D}, \qquad (3)$$

where:  $\lambda_s$  – additional coefficient of resistance, reflecting the presence of solids in the mixture, determined experimentally.

There are known attempts of creating analytical techniques of design [6, 7, 15, 24] but they are true for flows of low concentration (up to 5 kg/kg) only therefore are of not wide spread. The biggest part of industrial pneumatic conveying systems operate at the concentrations of 15–25 kg/kg and above.

In most commonly known works the semi-empirical design methods based on the

use of the experimental data have been suggested [2-4, 8, 9]. This fact does not provide the required accuracy of design. [10, 11, 13, 14, 16, 17, 19-22].

Thus by now a generalized technique of pneumatic conveying settled flows hydraulic design suitable for a wide range of pneumatic conveying conditions has not been developed yet.

#### WORK PURPOSE

The work purpose is the creation of scientifically based engineering techniques of hydraulic design of settled flows in horizontal pipes for industrial pneumatic conveying systems engineering with the purpose of their reliability and operation efficiency control.

## MATHEMATIC MODEL

Hydraulic equations of continuity, energy balance (analogue of the Bernoulli's equation), hydraulic resistances and gas equations serve as basic equations for solving tasks of gas suspension flow in the pipe at hydraulic design of pneumatic conveying systems. While writing them down we assume that the gas expansion process is isothermal and the flow is one dimensional, i. e. the mixture temperature during the conveying process is permanent and its density and concentration change while going from one pipe section to another one.

We assume the carrying medium as incompressible while considering the problem of specific pressure losses in the pipeline, i. e. at its short parts. under these conditions hydraulic equations of continuity and gas suspension motion are as following:

$$\rho_S S U_S = G_S \,, \tag{4}$$

$$\rho_a(1-S)U_a\omega = G_a, \qquad (5)$$

$$\rho_m \frac{U_m^2}{2} + P + \Delta P = const, \tag{6}$$

where:  $\rho_S, \rho_a, \rho_m$  – solids density, air density, air and solids mixture density respectively,

 $G_S, G_a$  – mass consumption of material and air,

P- pressure,

 $\Delta P$  – pressure losses at the pipeline part of *L* length.

The expression (6) is the Bernulli's equation for the gas suspension. The equation (6) is transformed, taking into account the respective dependencies, given in the works [21] and [8]:

$$\begin{bmatrix} \frac{1-S}{(1-C)^2} \cdot \beta_a + \frac{\rho_s}{\rho_a} \cdot \frac{S^3}{C^2 \cdot (1-S)^2} \cdot \beta_s \end{bmatrix} \cdot \beta_a \cdot \frac{U_a^2}{2} + , \quad (7)$$
$$+ P + \Delta P = const$$

where:  $\beta_a$  and  $\beta_s$  – non-dimensional coefficients, being analogues of Coriolis coefficient for the carrying agent flow. If however  $\beta_a$  takes the values 1.04÷1.1 for carrying agent,  $\beta_s$  may differ considerably from 1.

The equation (7) includes volume flow concentration S equal to the ratio of solids volume flow rate  $Q_S$  to the gas suspension  $Q = Q_S + Q_a$  volume flow rate, i. e.  $S = \frac{Q_S}{Q_S + Q_a}$ and the mean volume concentration *C*, taking into account the velocity fields asymmetry and concentrations in the pipe cross section. The concentration *S* and *C* functional connection obtained from the results of pipeline

conveying [18] hydraulic research:

$$S = C \left[ 1 - f \left( \operatorname{Re}_{S} \right) \left( 1 - \frac{C}{C_{\max}} \right)^{2,16} \left( \frac{u_{cr}}{u} \right) 1,66 \right], \quad (8)$$

$$f(\text{Re}_{S}) = 0,45 \left[ 1 + SignX \cdot th(0,967 |X|^{0,6}) \right], \quad (9)$$

$$X = \lg \operatorname{Re}_{S} - 0,88$$
, (10)

where:  $C_{\text{mas}}$  – limit volume concentration of solid material,

 $u_{cr}$  – critical velocity of pneumatic through horizontal pipeline, corresponding to

the beginning of solids falling on the pipe low wall,

 $Re_s$  – Reynolds number expressed through the free falling velocity  $w_s$  and solids mean diameter, i. e.

$$\operatorname{Re}_{S} = \frac{w_{S}d_{S}}{v_{g}},$$

where:  $v_g$  – gas kinematic viscosity.

Taking into account the fact that gas suspension volume concentrations are not big as a rule we assume that the Coriolis coefficient for the gas phase is 1, i.e.  $\beta_a \approx 1$ . Furthermore the values  $S \ll 1$  and  $C \ll 1$  of the first summand in the square brackets can be neglected as the value of the summand is much less than the second summand in these brackets. Taking into account the above mentioned and after some transformations the equation (7) can be reduced to the following form:

$$\begin{bmatrix} 1 + \frac{\mu^3 \left(\frac{\rho_a}{\rho_S}\right)^2}{C^2 \left(1 - \mu \frac{\rho_a}{\rho_S}\right)^2} \beta_S \end{bmatrix} \rho_a \frac{U_a^2}{2} + P + \Delta P = const, \quad (11)$$

where:  $\mu = \frac{G_S}{G_a}$  – mixture mass

concentration.

As it is known in hydraulics specific pressure loss in the pipeline  $\frac{\Delta P}{L}$  determined by the friction of the incompressible liquid is proportional to the specific (per the volume unit) kinematic energy of the flow  $\rho \frac{U^2}{2}$  which is expressed with the first summand of the left side of the Bernulli's equation (6) and determined by the Darcy – Weisbach formula:

$$\frac{\Delta P}{L} = \lambda \frac{1}{d} \rho \frac{U^2}{2} , \qquad (12)$$

where:  $\lambda$  – hydraulic friction coefficient, *d* – pipe drift diameter.

notation:

Passing from the fluid flow to the gas suspension flow and taking into account the expression in the round brackets of the left side of the Bernulli's equation (11) we write by analogy with (12):

$$\frac{\Delta P}{L} = \left[1 + \frac{\mu^3 \left(\frac{\rho_a}{\rho_s}\right)^2}{C^2 \left(1 - \mu \frac{\rho_a}{\rho_s}\right)^2} \beta_s\right] \lambda_m \frac{\rho_a}{d} \frac{U_a^2}{2}. \quad (13)$$

The expression (10) can be introduced the following way:

$$\frac{\Delta P}{L} = \varphi \frac{\Delta P_a}{L}, \qquad (14)$$

where:  $\frac{\Delta P_a}{L}$  – specific pressure losses while clean air movement:

$$\frac{\Delta P_a}{L} = \lambda_a \frac{\rho_a}{d} \frac{U_a^2}{2}, \qquad (15)$$

φ coefficient -

$$\varphi = \left[1 + \frac{\mu^3 \left(\frac{\rho_a}{\rho_s}\right)}{C^2 \left(1 - \mu \frac{\rho_a}{\rho_s}\right)^2} \beta_s\right] \frac{\lambda_m}{\lambda_a}.$$
 (16)

For the practical application of formula (11) we determine the parameters  $\lambda_a$ ,  $\lambda_m$  and  $\beta_s$ . As for the coefficients of hydraulic resistance  $\lambda_a$  and  $\lambda_m$  their values are equal in the quadratic realm of resistance as they do not depend upon Re<sub>a</sub> number. In case of pre quadratic realm of the hydraulic resistance the value  $\lambda_a$  is determined by Altschul formula:

$$\lambda_a = 0.11 \cdot \left[ \frac{68}{\operatorname{Re}_a} + \frac{K_e}{d} \right]^{0.25}, \qquad (17)$$

where:  $\operatorname{Re}_{a} = \frac{U_{a}d}{v_{a}}$  – the Reynolds number,  $v_{a}$  – air kinematic viscosity,  $K_e$  – relative roughness of the pipe inner walls.

The value  $\lambda_m$  is determined by the same formula (10) but taking into account the Reynolds number  $\text{Re}_a = \frac{U_a d}{v_m}$ , where the mixture viscosity can be determined by the formula:

$$\mathbf{v}_m = \mathbf{v}_a \frac{1+3,5C}{1+\left(\frac{\rho_S}{\rho_a}-1\right)C}.$$
 (18)

The functional dependency of the Coriolis coefficient  $\beta_s$  for a solid body from the determining parameters is deduced by processing the experimental data of measuring the specific pressure losses due the friction in the horizontal pipe.

If we assign  $\frac{\lambda_m}{\lambda_a} \approx 1$  that is correct for the flows of low concentration and introduce the

$$K = \left[\frac{\mu \frac{\rho_g}{\rho_S}}{C(1 - \mu \frac{\rho_g}{\rho_S})}\right]^2 \cdot \beta_S, \qquad (19)$$

 $\varphi = 1 + K_{\mu}$  in this case formula (16) is transformed to the Gastershtadt empiric formula (1).

The crucial significance of formula (16) is in its theoretical justification of the coefficient K dependence from its determining parameters.

The checking evaluation by formula (11) has shown their almost full coincidence with the experimental data. The design error is no more than 10 %.

#### CONCLUSIONS

1. The scientifically-based technique of the pneumatic conveying parameters design, based on the aerodynamic equations of continuity is suggested for the steady air disperse flow as a compressible medium. 2. The scientifically-based technique for determining and analyzing the coefficient included into the Geisterstadt formula is suggested.

3. The suggested formula (14) can be recommended for the hydraulic design of steady air disperse flows in the horizontal pneumatic conveying line.

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#### РАСЧЕТ ПОТЕРЬ ДАВЛЕНИЯ ПРИ ПНЕВМОТРАНСПОРТИРОВАНИИ СЫПУЧИХ МАТЕРИАЛОВ

#### Михаил Чальцев

Аннотация. Разработана новая, теоретически обоснованная методика гидравлического расчета аэродисперсных потоков в горизонтальном пневмотранспортном трубопроводе. Существующие методики носят эмпирический характер И справедливы лишь для ограниченного круга условий, близких к условиям эксперимента. Новая методика разработана на основе решения уравнения Бернулли для двухфазных потоков, с учетом новейших исследований в области гидротранспорта. Проверочные расчеты по новой методике показывают соответствие результатам экспериментальных исследований в широком диапазоне характеристик пневмотранспортных систем и транспортируемых материалов. Ключевые слова: пневматическое

транспортирование, аэродисперсный поток, гидравлический расчет, сыпучий материал

# Increase in efficiency of electric powered diamond grinding of conductive material by regulating longitudinal profile of grinding wheels

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S u m m a r y. The method of increasing the efficiency of electric powered diamond grinding of hard-tomachine materials which provides the reduction of vibration by forming rational longitudinal profile of working wheel's surface is presented. The prerequisites and peculiarities of vibration absorbing, technological equipment for implementing the suggested method are described.

Key words. Electric powered diamond grinding, wheel's working surface, longitudinal profile, vibration absorbing.

#### INTRODUCTION

Abrasive-diamond processing of hard-tomachine materials is widely used both at intermediate and final stages of producing essential components. Using diamond wheels for processing hard-to-machine materials is determined by unique physical, mechanical, thermal, electrical and chemical properties of diamonds grains. High hardness, stiffness, durability, cutting ability, elastic limits of diamond grains, homogeneity and density of their structure, low coefficient of thermal expansion, high thermal conductivity, low coefficient of friction [13] predetermine effective final processing of conductive materials.

At the present stage abrasive-diamond processing is characterized by searching the ways to increase the performance and economical efficiency of the process, quality and precision of parts-in-process. One of the factors, which in a great measure conditions the effectiveness of grinding is vibrational stability. The matters of increasing vibrational stability are of great importance due to development of flexible automated unmanned manufacturing. There is a new tendency in tool-making manufacturing - development of electromechanical devices and technological equipment that in their characteristics and functionality will conform to contemporary computer equipment [29].

The results of the investigation [3] prove that in the process of diamond grinding in due course the height of grain protrusion lowers, which leads to reduction of a tool's cutting abilities of processing and decrease performance; specific consumption of diamonds and vibrational amplitude increase. The waves of longitudinal profile of working surface, appearing as a result of processing and increasing in due time, negatively affects the process efficiency. It is fair to assume that by purposeful change of the waviness of working wheel's surface longitudinal profile, it is possible to regulate the outcome measures of grinding.

# RESEARCH ANALYLSIS

The efficiency of grinding is to a large extent determined by rational choice of the scheme and method of processing [6, 22]. Among the most advantageous ones are high speed [7], forced [8], cryogenic precision [19, 20], deep [14, 39], profile grinding [5, 39] etc. However, the choice of efficient kind of grinding not always guarantees the steadiness of working wheel's surface's relief and conditions of processing.

Stability of grinding process, as a part of its efficiency, is determined by stability of outcome measures of part processing during the whole period of operating. An important source of increasing the stability of processing is improvement of the equipment performance characteristics, defined by necessary stiffness, damping capacity, vibration resistance [1, 2, 15].

Grinding wheels with interrupted working surface are of big interest [18, 37], because they make it possible to increase significantly stability and the rate of the process outcome data [26, 36].

Introducing additional power in the cutting area [12, 21, 23, 33, 35] in some cases allows increasing the efficiency of grinding by means of keeping high cutting ability of a wheel. The increase in performance and quality of the processed surfaces in cases of imposing longitudinal vibration on the grinding wheel, while processing, is found out [34].

The systems of automated regulation of processing are used to consider changing conditions of grinding [38]. The most frequently regulated parameters are cutting force [32] or power [25], vibration level of the machine's parts [27]. Using such systems contributes to increasing stability of the quality of processed parts, but does not avoid the necessity for restoring the wheels' shape and cutting surface.

One of the main demands that establish the grinding efficiency is high cutting ability of diamond wheels. It can be reached by controlling the cutting relief by means of proportioned impact on the wheel's bond while grinding. It predetermines the wheel's operation in the mode, equivalent to the mode of self-sharpening in the absence of direct bond-to-processed metal contact, which contributes to reducing the cutting force and grinding temperature. However, in most cases the wheel's self-sharpening is insufficient for conducting high-efficiency processing, because the geometric form of its working surface does not remain unchanged.

Deviations of the working surface profile from the correct geometric form can appear in two mutually perpendicular directions. There are longitudinal waves and transverse waves. Longitudinal waves generally appear as a result of the technological system vibration. Transverse profile is defined by the inequality the wheel wearing [13]. It of was experimentally proved [28], that in cases of flat face grinding of the plates of hard-tomachine steels, longitudinal waviness is 15-20% bigger than transverse one.

The main factors that cause appearing the waviness in the course of grinding include: poor input shape precision and material of the part-to-process, characteristics and waviness of the grinding wheel's working surface, acquired as a result of tool dressing, the rate of its wearing and dulling, imbalance of the wheel and other machine units, damping capacity of the zone of wheel-to-part contact, stiffness and vibration stability of а technological system, grinding mode and cycle. Reducing negative impact of all the factors listed contributes to increasing the precision of the part's form [13]. Dead-stop grinding at the end of the operation cycle significantly reduces form defects [10]. The experiments proved [28], that thick grinding oil, got to the zone of tool-to-part contact, is able to reduce the amplitude of grinding pressure oscillations, lower the vibration rate in the technological system, which leads to decrease in waviness of the surface-to-process.

Controlling the working surface waviness in operation [10] means agreement of intensities of forced bond removal and linear wear of diamond wheels, as well as which defining the conditions exclude avalanchine falling of inactive grains out of bond. However, in such cases it is impossible to avoid changes in initial form of its working surface.

Reduction of waviness height can be reached by means of periodic changes of own vibration frequency in tool-to-part system [30]. The analysis of differential equations of cutting [16] proves, that the general solution is the process with momentum application of the force. A new notion of vibration insensitive cutting process was first introduced.

Direct relation between a pitch of waves  $t_B$  of longitudinal profile and a dynamic coefficient of the system  $\mu$ , [3]. which indicates how many times the amplitude of forced oscillations with excitation force is bigger than the system deviation, formed from the impact of pulsation of normal cutting force, was found  $\mu$  coefficient intensively decreases in case  $t_B$  lowers. Therefore, with the constant stiffness of the system *machine – equipment – tool – part*, providing rather short pitch of waves, it is possible to achieve a considerable reduce in vibration amplitude.

# **RESEARCH OBJECT**

Taking into account a considerable correlation between the parameters of the waves of longitudinal wheel profile and the oscillations of elastic cutting system, there are prerequisites for developing the method of grinding with the directional formation of longitudinal profile of the tool's working surface relief [4] with the parameters, that provide vibration reduction and continuous maintenance of its cutting characteristics.

In the course of investigations the method of reducing the oscillation amplitude of the cutting system by means of forming desired waves of grinding wheel's longitudinal profile was suggested. The theory of mechanical oscillation says that oscillation frequency of vibrating system deviates from the frequency of own oscillations in case if the forcing frequency has bigger value [16, 31]. Rational pitch of waves with pre-set grinding modes must provide additional pulsation of excitation force with the frequency, exceeding the frequency of the own vibration of the system. Electric discharge destruction of metal bond [17] by integrated grinding mode [4, 24] was chosen as the method of forming the wheel's working surface.

The choice of electric discharge impact on the wheel's bond (compared with electrochemical one) is determined by the following features:

- possibility to use ordinary cooling liquids instead of electrolyte, which lowers demands for corrosion resistance of materials,

- absence of oxide layer on the processed surface,

- high performance of electric diamond grinding with continuous electric discharge trueing of the wheel during the whole period of processing.

To implement the suggested method, the mechatronics system of regulating rational longitudinal profile of wheels' working surfaces on conductive bonds was developed. Block diagram of the system is presented in the figure.

Grinding wheel is electrically isolated from the machine. While processing the cutting zone is supplied with grinding oil. A voltage from impulse current source is applied to the grinding wheel and conductive part-toprocess. In this case there is electric discharge impact on the wheel metal bond and the part. Vibration measuring module records amplitude and frequency of grinding wheel vibration, an analog signal is generated and after digitizing DAC/ADC by m-DAQ12/DAC converter is sent to the computer and analyzed by a special program module. If the values of vibration amplitude and frequency exceed the



Fig. 1. Block diagram of mechatronics system of regulating grinding vibration



Fig. 2. The program of generating impulses of various forms

limits of pre-set range, the program generates digital control signal (Fig. 2), which is converted by m-DAQ12/DAC to analog one. It corrects the work of generator for changing current intensity and control impulse frequency.

The level of electric discharge impact on the grinding wheel bond must provide the height of longitudinal profile wave, significant for the influence on the vibrating cutting system, and is adjusted experimentally.

# **RESULTS OF RESEARCH**

On the considered theoretical grounds, a universal sharpener 3Д641E was modernized to implement the suggested ideas. In Fig.3 you can see electric isolation of the machine working parts and dielectric shell for the diamond wheel with four channels for current collector (Fig. 3).



Fig. 3. General view of the experimental machine

The synchronization module (Fig. 4) provides pre-set correlation of control impulse frequency and the wheel rotation for achieving desired pitch of longitudinal profile waves.



**Fig. 4.** The module for synchronizing frequency of current source impulses and frequency the grinding wheel rotation

The scheme of the module for measuring grinding vibration is presented in Fig. 5. This module is a springy cantilever beam with the fixed slide assembly for pattern and sample for treatment. The value of stiffness is regulated by moving the slide assembly along the spring beam. In the base plate there is a variable reluctance pickup of linear movements, which measures the vibration of cantilever beam while processing. Such scheme helps to evaluate the influence of pulsating component of cutting force, caused by processing with the diamond wheel with wavy working surfaces.

An original source of impulse technologic current was developed for an experimental machine (Fig. 6).



Fig. 5. Module for measuring grinding vibration



Fig. 6. The source of impulse technologic current

#### CONCLUSIONS

1. The suggested method of increasing the efficiency of diamond grinding of hard-tomachine materials provides reduction of grinding vibration by forming rational longitudinal profile of working wheel's surface. It helps to increase stability of grinding, reduce the tools wearing, improve dimensional accuracy and quality of processed parts' surface. The effect is achieved by electric discharge impact of electric impulse, synchronized with frequency of the wheel rotation on conductive diamond wheel's bond.

2. The existing level of mechatronics allows fulfilling the task of automated regulation of the rational vibration level for pre-set conditions of diamond grinding of hard-to-process materials.

3. Conducted modernization of universal sharpener 3Д641E provides implementation of the suggested method. The developed devices measure grinding vibration and synchronize frequency of technologic current control impulses and frequency the grinding wheel rotation.

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#### ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ ПРОЦЕССА ЭЛЕКТРОАЛМАЗНОГО ШЛИФОВАНИЯ ТОКОПРОВОДЯЩИХ МАТЕРИАЛОВ ПУТЕМ РЕГУЛИРОВАНИЯ ПРОДОЛЬНОГО ПРОФИЛЯ КРУГОВ

#### Владимир Доброскок, Андрей Шпилька, Марина Морнева, Николай Шпилька

Аннотация. Представлен метод повышения эффективности процесса электроалмазного шлифования труднообрабатываемых материалов, обеспечивающий снижение вибраций путем формирования на круге рационального продольного профиля рабочей поверхности. Рассмотрены предпосылки и особенности гашения вибраций, технологическое оборудование для реализации предлагаемого метода.

Ключевые слова: электроалмазное шлифование, рабочая поверхность кругов, продольный профиль, снижение вибраций.

# Dehydration of no flotation size coal's slimes on the deck of high-frequency screen with multislopes area's working surface

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S u m m a r y. The physical model of dehydration of coal slimes is offered on the deck of high-frequency screens as a process of the pulsating forming of inertia visco-plasticmaterial object, in which a coefficient of viscidity is the function of intensity of oscillation excitation.

Key words. Coal, dehydration, physical model, intensity of oscillation excitation.

# INTRODUCTION

During the coal slurry dewatering [20, 15, 14, 6, 22], solid phase volumetric concentration is increased due to water removal through the screen mesh. Thus coal slurry structural-mechanical properties [24, 1, 7, 8, 9] are substantially changed. Effective slurry viscosity is subject to the most significant alteration due to its nonlinear dependence on volumetric concentration of solid particles [16, 4, 27].

The processes of muds dehydration in coal's preparation's technology [25, 13, 10, 11, 26, 12] are widely used on high-frequency screens. Quality of products of dehydration to a great extent is determined the parameters of vibration of working surface of screen. However presently the adequate physical models of process absent dehydrations of suspensions' on a vibrating deck surface, allowing making the choice of optimum regime parameters.

In the article the attempt of development of physical model of dehydration's process at motion of stream of suspensions' is done on a vibrating deck at the monotonous decline of liquid phase concentration.

# **RESEARCH ANALYSIS**

Slurry elastic characteristics are resulted from the air bubbles presence. However, during dewatering on the screen sieve accompanied by the layer vibration thickening air bubbles are intensively released through the free layer surface and through its bottom boundary, i.e. through the screen. Thus, slurry layer on the screen may be assumed as a viscoplastic rheological body.

High-concentration slurry is characterized by the spatial structure resistive

to stress not exceeding certain  $\tau_c$ , value designated as shear stress or yield strength [28]. In case that material stress exceeds the yield strength, its structure collapses, and shearing flow occurs, of which rate is proportional to excess shear velocity, i.e., material behaves as a Newtonian fluid at the shear stress  $\tau$ - $\tau_c$ .

# **RESEARCH OBJECT**

It is known [20] that dehydration's process of suspensions' on a vibroscreen it is possible to divide conventional into three stages.

On the first stage, characterized considerable maintenance of liquid phase, there is preliminary dehydration, conditioned hydrostatical pressure mainly layer suspensions', on the second stage the process of dehydration is conditioned the inertia constituent of vibrations, providing tearing away of free moisture from sticespace of layer of material, on the third stage the process of dehydration takes a place due to the vibrocompression of material layer attended with the selection of free moisture from sticespace space layer.

On the first stage an initial suspensions', given on a screen, has an enough low concentration of liquid phase and can be examined as a homogeneous liquid with effective viscidity, exceeding viscidity of liquid phase. For the small concentration of the self-weighted particles of regular shape effective viscidity of suspensions' is calculated on simple formulas [15]. Oscillation influence is elevated by suspensions' viscidity, as amplitudes of particulate matters' vibrations less amplitude of liquid's particles vibrations. Therefore for the case of small concentration of particulate matters selection of liquid phase through openings of deck more effective for an immobile sifting surface. If speed of suspensions' flow on a deck is not very much high, expiration of liquid through openings of deck will be determined the depth of suspensions' stream.

Deformation of viscoplastic material results in occurrence of stress  $\tau = \eta \dot{\epsilon} + \tau_c$ , where  $\eta$  is viscosity coefficient, and  $\dot{\epsilon}$  is rate of deformation.

Let us consider a viscous material behavior on the harmonically oscillating horizontal sieve surface under the unseparated conditions.

Let us distinguish unit cross-section bar in the material layer with axis coinciding with the pressure load normal component on the screen side. The bar height is equal to the material layer thickness h and bar mass  $m = \rho h$ , where  $\rho$  is the material density.

Material layer is subject to harmonic exciting force  $F \cos \omega t$ , where F and  $\omega$  are the exciting force amplitude and frequency, and tis the time. In addition, during the oscillation layer is subject to inertia forces due to the material density  $\rho$ , viscous friction forces and dry friction forces determining the material plastic deformation.

The screen surface vibration normal component results in layer deformation and facilitates its dewatering, while the tangent component provides layer vibratory displacement. Therefore, when taking account of vibration normal component only, we assume that layer inertia force will be  $m\ddot{y} = \rho h\ddot{y}$ , where y is layer vertical displacement,  $y = \varepsilon h$ .

Viscous friction force in the material layer is equal to  $\eta \dot{y}$ , where  $\dot{y} = h\dot{\epsilon}$  is the layer vertical displacement velocity.

Dry friction force  $\vec{R}$  is constant in magnitude and is directed oppositely to displacement velocity  $\vec{R} = -R\dot{y}/|\dot{y}|$ , where *R* is constant depending on the friction coefficient and cohesive force. If force  $\vec{R}$  is resulted from the stress exerted upon the lateral surface of the square bar, then  $R = 4h\tau_c$ . Assuming the permanent plastic deformation during the layer vibration thickening, we will represent dry friction force as  $R(\text{sgn }\dot{y}+1)/2$  [17,18], where:

$$\operatorname{sgn} = y \begin{cases} 1 & at \quad y > 0, \\ -1 & at \quad y < 0. \end{cases}$$

Thus, layer plastic deformation occurs, if screen displacement velocity is directed upward, and the stress in layer exceeds ultimate shear stress  $\tau_c$ . If screen velocity is directed downward, then dry friction force is equal to zero, and layer moves as an inertia body.

Fig.1 shows dynamic computational diagram of the inertia viscoplastic body being subject to harmonic exciting force.

The equation for layer motion on the vibrating surface takes the following form based on the assumed dynamic design:

$$m\ddot{y} + \eta\dot{y} + 2h\tau_c \left(\operatorname{sgn} \dot{y} + 1\right) = F \cos \, \varpi t.$$
 (1)

Layer height varies slowly at the final



The equation (1) includes nonlinearity due to the function sgn  $\dot{y}$ . Such type equations are solved with the use of methods of step-bystep integrating or methods based on the motion equation linearization [2].

In order to reduce equation (1) to the linear form we will use the power balance method [19, 3, 21, 5, 23] whereby nonlinear dry friction force can be replaced with the energy equivalent linear force  $b_0 \dot{y}$ , for which coefficient  $b_o$  is determined based on the condition of equality of the works done by both forces over the oscillation period [24], i.e.:

$$\int_{O}^{T} \tau_c \operatorname{sgn} \dot{y} \cdot \dot{y} \cdot dt = \int_{O}^{T} b_o \dot{y}^2 dt.$$
(2)

We cam assume for a first approximation that oscillatory process is harmonic in the steady conditions.

One can see from the equation (1) that nonlinear friction force presents at the positive velocity values only, and function sgn  $\dot{y}$  takes on values 0 and 1. Therefore expected oscillatory law for the layer displacement velocity will be:

$$\dot{y} = -a\varpi\sin\omega t, \qquad (3)$$

where: *a* is the layer oscillation amplitude.

Insertion of expression (2) into (3) results as follows:

$$\int_{O}^{T} b_o \dot{y}^2 dt = b_o a^2 \varpi \int_{O}^{2\pi} \sin^2 \psi d\psi = b_o \pi a^2 \varpi, \quad (4)$$

where:  $\psi = \omega t$ .

Let us calculate an integral on the left part of (2) for the nonlinear resistance force:

$$\int_{O}^{T} \tau_{c} \dot{y} \operatorname{sgn} \dot{y} \cdot dt = -\tau_{c} a \int_{O}^{2\pi} \sin \psi \operatorname{sgn} \dot{y} \cdot d\psi =$$
$$= 4\tau_{c} a.$$
(5)

Equating results of calculations of (4) and (5) allows determination of equivalent friction coefficient:

$$b_o = \frac{4}{\pi a \varpi} \tau_c$$


Once the coefficient  $b_o$  is determined, the problem reduces to investigation of the equivalent linear dynamic system where the dry friction force is as follows:

$$2h\tau_c\left(\operatorname{sgn}\dot{y}+1\right)\approx 2h\tau_c\left(b\dot{y}+1\right),\,$$

where:  $b = 4/\pi a\omega$ .

In case of the system with the non-elastic resistance, oscillatory motions lag behind the exciting force. Therefore, if oscillatory motions follow the low  $y = a \cos \omega t$  as a first approximation, then law of variation of exciting force can be on written as  $F \cos(\omega t + \varphi)$ , where  $\varphi$  is phase angle. Then the motion of the linearized dynamic system will be described by equation:

$$m\ddot{y} + (\eta + 2bh\tau_c)\dot{y} + 2h\tau_c = F\cos(\varpi t + \phi).$$
(6)

At the moments of maximum system departure from the equilibrium point when  $cos \omega t = 1$ :

$$F\cos\phi=2h\tau_c-ma\varpi^2,$$

and at the moment of equilibrium point passage  $cos \omega t = 0$  and:

$$F\sin\phi = (\eta + 2bh\tau_c)a\varpi - 2h\tau_c.$$

After the last equalities squaring and addition, we will obtain following expression associating the exciting force value and system oscillation amplitude:

$$F^{2} = \left(2h\tau_{c} - ma\varpi^{2}\right)^{2} + \left(Ba\varpi - 2h\tau_{c}\right)^{2}, \quad (11)$$

where:  $B = \eta + 2bh\tau_c$ .

Thus oscillation phase is as follows:

$$\phi = \arccos \frac{2h\tau_c - ma\varpi^2}{F}.$$

Equation (6) is linear with respect to  $\dot{y}$ , and its solution is known:

$$\dot{y} = \ell^{-\frac{B}{m}t} \left\{ \int \left[ \frac{F}{m} \cos\left(\varpi t + \phi\right) - \frac{2h\tau_c}{m} \right] \ell^{\frac{B}{m}t} dt + C_o \right\},\$$

where:  $C_o$  is the initial value. Solving this integral at the initial condition:

$$\dot{y} = 0$$
 given  $t = 0$ ,

we obtain:

$$\dot{y} = \frac{2h\tau_c}{B} \left( \ell^{-\frac{B}{m}t} - 1 \right) + \frac{Fm}{B^2 + m^2 \varpi^2} \times \left[ \frac{B}{m} \cos\left(\varpi t + \phi\right) + \varpi \sin\left(\varpi t + \phi\right) - \left( \frac{B}{m} \cos\phi + \varpi \sin\phi \right) \ell^{-\frac{B}{m}t} \right].$$
(11)

The solution (11) describes the layer velocity variation with account for the transient process in the initial time period. The expression (11) can be rewritten for the steady-state process  $t \rightarrow \infty$  as follows:

$$\dot{y} = \frac{Fm}{B^2 + m^2 \varpi^2} \left[ \frac{B}{m} \cos(\varpi t + \phi) + \varpi \sin(\varpi t + \phi) \right] - \frac{2h\tau_c}{B}.$$

Integration of expression (11) at the initial condition  $y = h_o$  at t = 0 results in determination of the vibrating layer displacement:

$$y = h_o - \frac{2h\tau_c}{B} \left[ t - \frac{m}{B} \left( 1 - \ell^{-\frac{B}{m}t} \right) \right] + \frac{Fm}{B^2 + m^2 \varpi^2} \times \left[ \frac{B}{m \varpi} \sin(\varpi t + \phi) - \cos(\varpi t + \phi) + \left( \cos \phi + \frac{m \varpi}{B} \sin \phi \right) \ell^{-\frac{B}{m}t} - \frac{B^2 + m^2 \varpi^2}{m \varpi B} \sin \phi \right].$$

In steady-state process  $(t \rightarrow \infty)$ :

$$y = h_o - \frac{2h\tau_c}{B}t + \frac{Fm}{B^2 + m^2\varpi^2} \times \left[\frac{B}{m\varpi}\sin(\varpi t + \phi) - \cos(\varpi t + \phi) - \frac{B^2 + m^2\varpi^2}{m\varpi B}\sin\phi\right].$$

The solution describes material layer surface displacement at the oscillatory shear flow and includes evolutionary:

$$y_1 = h_o - \frac{2h\tau_c}{B}t - \frac{F}{\varpi B}\sin\phi$$

and oscillatory:

$$y_2 = \frac{Fm}{B^2 + m^2 \varpi^2} \left[ \frac{B}{m\varpi} \sin(\varpi t + \phi) - \cos(\varpi t + \phi) \right]$$

components. The layer vibration thickening process takes place without its mass variation at the constant resistance. It is reasonable that the layer thickening is only possible when the stress in material exceeds shear stress  $\tau_c$ .

Evolutionary component of thickening rate under the steady-state conditions  $dy/dt = -2h\tau_c/B$ . Here the layer height *h* is present as a parameter.

Concentrated slurry viscosity coefficient depends on the vibration parameters as follows:

$$\eta = \eta_o + \frac{k}{a\varpi^3},$$

where: k is the constant coefficient, and  $\eta_o$  is the residual viscosity coefficient due to the oscillatory thixotropic destruction of dispersion medium.

Then the rate of material layer thickening on the vibrating screen:

$$\frac{dy}{dt} \approx -\frac{2h\tau_c}{\eta_o + \frac{k}{a\varpi^3} + \frac{8h\tau_c}{\pi a\varpi}}$$

Parameters  $\tau_c$ ,  $\eta_o$  and k included in this formula are subject to the experimental determination.

Fig. 2 shows plots of layer thickening rate against working surface vibration amplitude and frequency. Exemplary material parameters for the layer of h = 0.1 m are assumed as follows [12,13]:  $\tau_c = 10$  N/m<sup>2</sup>,  $\eta_o = 10^3$  M·s/m<sup>2</sup>,  $k = 10^6$  N/m·s<sup>2</sup>.



**Fig. 2.** Viscoplastic material vibration thickening rate vs. working surface vibration amplitude and frequency:

$$y(v) npu a=1 mm,$$
  
 $\dot{y}(a) npu v = 75 pad / c.$ 

#### **RESULTS OF RESEARCH**

On the first stage there is a translation of coal suspensions' in highly concentrated due to the upcast of free-drying.

On the second stage the translation of highly concentrated suspensions' is carried out in viscoplastic material due to the delete of external moisture.

Beginning of the third stage corresponds the state of the water saturated system of particulate matters, at which regular contacts have particles with each other. On this stage the process of dehydration is already determined the vibrocompression' process of particles of hard phase and delete of the liquid freed from interparticle space through a deck.

It is known that its rheological properties change during the vibration of the structured suspensions'. It is experimentally set [3] that deformation of mixture (or its speed) at unchanging as compared to static middle tension is increased in  $\left[1+\alpha\left(A\omega^2/g\right)\right]\psi(Ti)$  one times, where Aand  $\omega$  accordingly, amplitude and frequency of vibrations,  $\psi(Ti)$  it is a function of specific thixotropic, depending on granule compositions and circulating in unit in default of vibration, g it is an acceleration of gravity,  $\alpha$  it is a constant.

Between the modes of vibration and viscidity of highly concentrated suspensions many authors were engaged in the decision of problem of establishing a connection [14]. Semiempiric formulas, including the different criteria of intensity of vibration, are got as a result. The most reliable are consider the criterion of intensity and dependence of viscidity from the mode of vibration, where is viscidity of the fully blasted structure. Thus, quality of dehydration on this stage substantially depends on the parameters of vibration of dehydrating surface.

It is set [6] that the compression of dispersible environment is determined in size accelerations of the vibrations put to it. Thus, the optimum value of acceleration depends on physic-mechanical properties of environment. The compression of environment takes a place because of decline of forces of friction between particles due to the action of inertia forces and gravities.

It is experimentally set [6] that at influence of vibration with the optimum for a compression acceleration of particle of environment with a high-slay and largenesses can walk up a surface layer. This phenomenon is explained the difference of values of optimum accelerations for the particles of different largeness and closeness in the process of vibrocompression.

It is known also, that at more highfrequencies a maximal compression is arrived at less amplitudes. However with the increase of frequency the degree of maximal compression goes down. Growth of amplitude of vibrations only to the known limit is instrumental in the increase of closeness. The certain most usefully frequency of vibrations, cooperated achievement of maximal compression, corresponds every value of amplitude. The results of researches of influence of duration of process of vibrocompression rotined on the degree of compression [6], that the process of compression flowed unevenly with decreasing speed: more intensively in initial moment, and then speed of compression diminishes. Such unevenness is explained that as far as the compression of environment the area of surfaces of contact between particles is increased, what efficiency of influence of vibration goes down because of.

On the third stage dehydration of suspensions is carried out in two stages [22]: overstowage of particles of hard phase and their rapprochement.

On the stage of overstowage under the action of vibration there is destruction and alteration of unsteady casual structure of particles which under the action of gravity aim to occupy the most advantageous power position.

Reason of destruction of the structured system of dispersible particles is relative inertia displacement of particles of hard phase of different closeness and size.

This relocation bias the more than anymore mass of particle, higher acceleration of vibrations, anymore difference of closenesses of particle and environment, than less than viscidity of the system. At the end of the stage of overstowage the system acquires a steady structure.

On the stage of rapprochement of substantial change of structure of particles does not take a place. The compression of mixture is carried out as a result of rapprochement of particles, their moving apart and relative changes, that is conditioned not only vibroinfluence but also redistribution on volume of liquid phase. Time of the second stage considerably anymore duration first. On this stage at relative displacement of particles there is «wringing» out of liquid phase from the pores of mixture.

On the final stage of dehydration formation of the thixotropic structured system, formed as a result of coagulative co-operations is possible. As a result of action of effect of the oscillation work-hardening of structure formation of the new work-hardened contacts is possible, that results in formation of hard dispersible structure.

On the basis of the expounded pictures of process of dehydration the simplified dynamic model layer suspensions on the working surface of vibroscreen can be interpreted visco-plastical rheological body with the added mass, to equal mass of bar of single section the height of which is equal to the height of layer of dry material, and a closeness is equal to the closeness of suspensions. As a result of action of vibration there is a limit of fluidity of material  $\sigma_o \rightarrow 0$ , and tension in a plastic element proportionally deformations:  $\sigma_n = k_{\Pi} \varepsilon_{\Pi}$ , where  $k_{\Pi}$  is a coefficient of plasticity, and  $\epsilon_{\pi}$  is deformation of plastic element. In addition, suppose that the height of layer of water-free material is equal to  $h_m$ , and then tension in a plastic element on the stage of compression of layer proportional to  $(h_1 - h)/(h_1 - h_m)$ , that is to say resistance a flowage changes from zero to  $k_{\Pi}$ .

We suppose that a height of layer of the dehydrated material h = h(t) is a slowly changing parameter, remaining unchanging during one period of vibrations of working surface. Then equalization of motion of layer of the dehydrated material on the sieve of crash under the action of the pulsating loading  $F_o \sin \omega t$ , proper the i-period of vibrations, it will be:

$$\rho h(t) \ddot{y} + K \dot{y} + \frac{h(t)}{h(t) - h_m} k_{\Pi} y = F_o \sin \omega t.$$
(12)

where:  $\rho$  is a closeness of the dehydrated material, *K* it is a coefficient of viscid resistance,  $F_o$  and  $\omega$  accordingly, amplitude of revolting force and frequency of the forced vibrations of working surface of screen.

Because layers deformation is irreversible and developing only in the direction of decline, during the semiperiod of vibrations a layer moves as a solid by mass, and during the second semiperiod as inertia visco-plastical Bingham's body in accordance with equalization (12).

The decision of equalization (12) is searched in a kind:

$$y = A_i \sin \omega t + B_i \cos \omega t \,. \tag{13}$$

After the substitution of expression (13) in equalization (12) expression (13) can be presented in a kind:

$$A_{i} = F_{o} \frac{\frac{h_{1} - h_{i}}{h_{1} - h_{m}} k_{\pi} - \rho h_{i} \omega^{2}}{\left(\frac{h_{1} - h_{i}}{h_{1} - h_{m}} k_{\pi} - \rho h_{i} \omega^{2}\right)^{2} + K^{2} \omega^{2}},$$
$$B_{i} = \frac{F_{o} K \omega}{\left(\frac{h_{1} - h_{i}}{h_{1} - h_{m}} k_{\pi} - \rho h_{i} \omega^{2}\right)^{2} + K^{2} \omega^{2}}.$$
$$V = a_{i} \sin(\omega t + \varphi_{i}),$$

where:

$$a_{i} = \sqrt{A_{i}^{2} + B_{i}^{2}} =$$

$$= F_{o} \left[ \left( \frac{h_{1} - h_{i}}{h_{1} - h_{m}} k_{\Pi} - \rho h_{i} \omega^{2} \right)^{2} + K^{2} \omega^{2} \right]^{-\frac{1}{2}},$$

$$\varphi_{i} = \operatorname{arctq} \left( B / A \right) = \operatorname{arctq} \frac{K \omega}{\rho h_{i} \omega^{2} - \frac{h_{1} - h_{i}}{h_{1} - h_{m}}}$$

Thus, the vibrations of surface of layer of the dehydrated material take a place with frequency of the forced vibrations, and the change of phase in the i-period of vibrations is equal  $\varphi_i$  and depends on a layers height.

There is a height of layer of the dehydrated material  $h = h_1$  in initial moment of compression. Thus a flowage is equal to the zero and motion of material is characterized inertia and viscous resistances. As far as diminishing of height of layer arise up and

plastic resistances increase further. The algorithm of calculation of changing height of layer consists of the following.

We suppose  $h = h_1$  and on formulas (12) calculate coefficients  $A_i$  and  $B_i$ . Then on a formula (12) determined  $a_1$  – amplitude of vibrations in the direction of diminishing h for the first period of vibrations of process of compression.

Then, for first period of vibrations the change of materials layer height will make  $\Delta h_1 = F_o / (\rho h_1 \omega^2) - a_1$ . At the beginning of the second period (i=2) of vibrations  $h_2 = h_1 - \Delta h_1$ . Repeating calculations will define  $\Delta h_2 = a_1 - a_2$ ,  $h_3 = h_2 - \Delta h_2$  et cetera. Iteration process continued to achievement of time  $t = i/2\pi\omega$ , equal time of unloading of water-free material from the deck of screen. For example, at frequency of unbalance screens billow rotation of 150 radian/sec, to of materials middle speed portage at dehydration 0,1 m/sec and to length of deck area on which the process of vibrocompression is provided actually, equal 2 m, and iteration count will be 3000.

### CONCLUSIONS

1. These data enable length calculation for screen dewatering surface devices, where the first device is designed for the material dewatering with the prevailing use of hydraulic principles, while the second one is designed for dewatering due to the laws of inertial mixtures mechanics.

2. Thus, on the basis of presentation of dehydration process of suspensions on a vibroscreen, as a process of pulsating deformation of inertia viscoplastic body, a dynamic model, answering equalization (12) in which a coefficient of viscidity is the function of intensity of oscillation influence, is offered  $A\omega^2/g$ .

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#### ОБЕЗВОЖИВАНИЕ УГОЛЬНОГО ШЛАМА НА СИТЕ ВЫСОКОЧАСТОТНОГО ВИБРАЦИОННОГО ГРОХОТА С РАЗНОНАКЛОННЫМИ УЧАСТКАМИ РАБОЧЕЙ ПОВЕРХНОСТИ

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Аннотация. Предложена физическая модель обезвоживания угольных шламов на высокочастотных вибрационных грохотах как процесс пульсирующего формирования вязкопластичного материала, в котором коэффициент вязкости является функцией интенсивности возбуждения колебаний.

Ключевые слова: уголь, обезвоживание, физическая модель, интенсивность возбуждения колебаний.

# Synthesis of test actions for capacitive moisture meter that is invariant to change of substance type

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Summary. In the article the research of various test actions to ensure invariance of capacitive moisture meters to change of substance type is carried out. The analysis of ways to reduce uncertainty of substance type is carried out. The most perspective direction of researches – test methods is chosen. The algorithm of a test method and the block diagram of measuring system for additive and multiplicative tests are chosen. During calculations the expression for determination of substance moisture content that is invariant to change of dielectric permeability is obtained. For the purpose of approbation of this expression the results of check of dependence of moisture content from dielectric permeability are received. Pearson criterion is applied for determination of results consistency. It is determined that these results rather well compensate the uncertainty of substance type.

K e y w o r d s. Capacitive moisture meter, uncertainty of substance type, test method, additive test, multiplicative test.

#### **INTRODUCTION**

One of the most widespread productquality indexes is moisture [5]. Moisture is an important factor at control of parameters and control of technological processes in industry and in production of various materials [3, 14, 19]. For many types of agricultural production (grain and fodders) moisture is the factor that shows a share of nutrients in production and duration of its storage [12, 13, 16, 18].

In industry it is often necessary to analyze moisture of petroleum products, bulks, building materials and other substances directly in technological process without using bulky samplers. For the solution of an objective and some other tasks the capacitive method for moisture measurement has gained the most widespread.

Advantages of capacitive moisture meters are first of all the possibility to control moisture in wide range with high accuracy, efficiency of measurements and no damages on the measured sample [1]. The main disadvantage is presence so-called uncertainty of substance type associated with the fact that the values of dielectric permeability significantly differ not only for various substances but also for various brands of the same substance [21].

Thus the most important direction of researches in the field of capacitive moisture meters is reduction of substance type uncertainty that will allow using these moisture meters for measuring of substances moisture content because they have a number of advantages.

## ANALYSIS OF PUBLICATIONS

Today there are some ways to solve the uncertainty of substance type for measuring of moisture of substances using capacitive moisture meters [4, 17, 20]. One of such ways is input of calibration curves in memory of moisture meters. These curves have information about dielectric permeability of substances that can be used in the measurement process. However it is obvious that the amount of substances and types of these substances is so great that to consider all possible dielectric permeabilities isn't possible.

Another way is providing of moisture meters with a calibration tables (moisture meters of Kett, IVZ-M1, IVZ-M1T, WILE-55, Sinar AP 6060, Kaplya, Grain Master, VSN-100. VSP-6P, Mu1ti Grain. FAUNA, Farmpoint, GAC500, HE-50, Superpoint types) [11]. These tables are created on the basis of experimental data about dielectric characteristics of moisture containing materials. Use of these data requires some caution as the results of measurements that have been carried out in different conditions and with different methods don't coincide and sometimes contradict each other [1].

One of the ways is carrying out of moisture meters calibration for the specified structure of substance. Thus the moisture meter ceases to be universal as the measurements of moisture are possible only for that structure of substance for which a calibration was carried out. Moreover the most important is the fact that accuracy of analytical methods of moisture meters calibration in many cases not more than accuracy of calibrated device [1]. The shortcomings given above and also bulkiness and labor input of the calculations connected with the use of calibration don't allow the use this method to solve the uncertainty of substance type.

One of the perspective directions is use so-called "test methods" that allow to reduce influence of substance type on the moisture content value [2, 15]. The essence of these methods consists in generation of test actions by means of injection a known amount of water or dielectric substance with the set dielectric permeability in initial substance. Thus the result of measurement is determined by change of dielectric permeability of initial sample after test actions with use of test methods.

With a research objective of this direction in early works [6, 21, 22] synthesis and tests of effective ways of test algorithms formation were carried out. These test algorithms would allow the compensating of uncertainty of studied substance type substances in conditions close to real polarizing processes in dielectrics and with a minimum of restrictions. Thus in [22] it is presented a method for formation and research of invariant test algorithm with the use of least-squares method (LSM), and in [6] – with the use of an interpolation Lagrange's polynomial. The researches conducted in these works showed that compensation of change of dielectric permeability of dehydrated substances is carried out in insufficient degree. Thus application of test methods for the solution of objectives requires more careful research.

#### PURPOSE OF RESEARCH

Objective of this research is check of possibility of test methods using for solving the uncertainty of substance type problem for capacitive moisture meters.

### **RESULTS OF RESEARCH**

Generally at test methods the measuring process consists of several steps. In the first step (the main) the measured value is defined and in others steps an additional tests are carried out each of which is some function of the measured value [2].

So let we have the substance that dielectric permeability is unknown. For an exception of this value at determination of moisture content it is necessary to carry out some additional tests. In the previous works [6, 21, 22] such tests were formed by addition of some in advance known amount of water in studied substance. Thus dielectric permeability of initial sample of substance was equalled  $\varepsilon_1$ .

In the first test dielectric permeability of the same sample after addition of a known amount of water was received ( $\varepsilon_2$ ). The second test was formed by adding to the sample of the first test still the same amount of water. However as the results of calculations showed such approach didn't allow to get rid completely of the problem of substance type uncertainty.

For the solution of objective the various test algorithms are analysed by authors. As a perspective the algorithm consisting in carrying out of independent additive and multiplicative tests is chosen.

There are some ways of measuring systems (MS) construction for realization of chosen algorithm. Block diagrams of MS for additive and multiplicative tests with three keys is presented in Fig. 1.



**Fig. 1.** Block diagram of measuring system for additive and multiplicative tests with three keys: UAT – unit of additive test; UMT – unit of multiplicative test; MD – measuring device; CD – computing device; K – key

For this diagram process of measurement consists of three steps. In the first step keys K1 and K2 are disconnected, and key K3 is closed and on input of measuring device (MD) measured value – moisture is directly supplied. In the second step K1 is closed and on input of MD additive test is supplied. In the third step K3 is disconnected, and K2 is closed connecting output value  $k \cdot W$  of unit of multiplicative test (UMD) on input of MD. Results of transformations are transferred from output of MD in computing device (CD).

Thus independent additive tests can be presented in the form of the sum:

$$W_{ad} = W + \Delta W , \qquad (1)$$

where:  $W_{ad}$  – value of substance moisture content received after carrying out of additive test, W – measured value of moisture content,  $\Delta W$  – constant component of additive test which is uniform and independent value from W, and is a water addition.

Independent multiplicative tests can be presented in the form of product:

$$W_{mult} = k \cdot W , \qquad (2)$$

where:  $W_{mult}$  – value of substance moisture content received after carrying out of multiplicative test, k – coefficient of transformation which is independent from Wand represent a certain multiplier.

The block diagram of MS differing by presence of the adder and the block diagram without influence of conversion coefficient are presented in Fig. 2.

The diagram with two keys and adder (Fig. 2, a) is used in case it is impossible to include a key K3 in a chain of the measured value. Thus the additive test will be the same as in the first case:  $W_{ad} = W + \Delta W$ . The result of multiplicative test can be presented as a sum:  $W_{mult} = k \cdot W + W$ .

The advantage of the block diagram presented in Fig. 2, b is the possibility of an exception of influence of transformation coefficient of UMT on the result of measurement. In this case process of consists four measurement of steps: measurement of moisture content value W, additive test  $W_{ad} = W + \Delta W$ , multiplicative test  $W_{mult} = k \cdot W$  and  $k \cdot W + k \cdot \Delta W$  test type.



**Fig. 2.** Block diagram of measuring system for additive and multiplicative tests: a – with two keys and adder, b – without influence of conversion coefficient

For realization of the test method chosen by authors the most suitable diagram is the block diagram presented in Fig. 1 as it allows to receive a necessary number of tests of a certain type.

For the purpose of implementation of possibility of application of test method for capacitive moisture meters at this stage we will consider tests creation for liquid dielectrics (for example petroleum) [9].

Taking into account that test conditions have to be at least two during researches we will receive: capacity of primary measuring transducer (PMT) with initial sample of substance ( $C_1$ ), capacity of PMT with the same sample after addition of the set amount of water ( $C_2$ ) (additive test) and capacity of PMT with initial sample of substance at carrying out of measurements k times ( $C_3$ ) (multiplicative test). This is sufficient for the formation of a system with three equations solving which we will receive expression for determination of substance moisture content.

Thus using a linear dependence given in [21] we will receive:

$$\begin{cases} C_1 = \varepsilon (1+3W)g, \\ C_2 = \varepsilon (1+3(W+\Delta W))g, \\ C_3 = k \cdot \varepsilon (1+3W)g, \end{cases}$$
(3)

where:  $\varepsilon$  – dielectric permeability of studied substance; g – spatial characteristic of

electric field of the gap created by a form of electrodes chosen by PMT, equal 10 m;  $\Delta W$  – addition of water for additive test, equal 0,1 (10%); k – coefficient for multiplicative test, equal 2.

For the solution of Eq. 3 the differential method offered in [8] is used:

$$\begin{split} & C_2 - C_1 = 3\varepsilon g \Delta W \,, \\ & C_3 - C_1 = \varepsilon g (k-1)(1+3W) \,, \\ & \frac{C_3 - C_1}{C_2 - C_1} = \frac{(k-1)(1+3W)}{3\Delta W} \,, \end{split}$$

from which:

$$W_{calc1} = \frac{\Delta W(C_3 - C_1)}{(k-1)(C_2 - C_1)} - \frac{1}{3},$$
 (4)

Thus from Eq. 4 it is visible that moisture content of substance doesn't depend on dielectric permeability at using the offered test algorithm.

Check of Eq. 4 on invariance is carried out with the use of formulas:

$$C_1 = g \cdot \varepsilon_1 \,, \tag{5}$$

$$C_2 = g \cdot \varepsilon_2, \tag{6}$$

$$C_3 = g \cdot \varepsilon_1 \cdot k , \qquad (7)$$

where:  $\varepsilon_1$  – dielectric permeability of initial substance;  $\varepsilon_2$  – dielectric permeability

of substance with addition of water  $\Delta W$ , equal 0,1 (10 %).

As change of dielectric permeabilities  $\varepsilon_1$ and  $\varepsilon_2$  in range of humidity from 0 % to 15 % is nonlinear as mathematical dependence we use Winer's formula allowing rather adequately to describe polarizing processes for a wide class of binary dielectric systems [10].

$$\varepsilon_{1} = \varepsilon \left( 1 + \frac{3W}{\frac{\varepsilon_{W} + 2\varepsilon}{\varepsilon_{W} - \varepsilon} - W} \right), \tag{8}$$

$$\varepsilon_{2} = \varepsilon \left( 1 + \frac{3(W + \Delta W)}{\frac{\varepsilon_{w} + 2\varepsilon}{\varepsilon_{w} - \varepsilon} - (W + \Delta W)} \right), \qquad (9)$$

where:  $\varepsilon_w$  – dielectric permeability of water, equal 80.

So let dielectric permeabilities of some virtual group of substances equal 2,0; 2,5; 3,0 and 3,5. We will change moisture of these substances by addition of water into them from 0 (0%) to 0,3 (30%) with a step of 0,1 (10%). The calculated values of dielectric permeabilities are given in Table 1.

Table 1. Calculated values of dielectric permeabilities

Moisture	Dielectric permeability (ε)			
content	for	for	for	for
(W)	$\epsilon = 2$	$\epsilon = 2,5$	$\epsilon = 3$	$\epsilon = 3,5$
0	2,0	2,5	3,0	3,5
0,1	2,614	3,252	3,385	4,512
0,2	3,368	4,173	4,963	5,741
0,3	4,317	5,324	6,305	7,262
0,4	5,545	6,806	8,022	9,197

Having substituted in equations (5), (6), (7) known values we will receive capacities  $C_1$ ,  $C_2$ ,  $C_3$  of PMT which are necessary for determination of calculated value of moisture content according to the Eq. 4. Results of calculations of substance moisture content are given in Table 2.

Obvious is that fact that with the increase of substance moisture content W the calculated value of moisture content  $W_{calc}$  also has to increase. As evident from results presented in the Table 2 the monotonous increase of values of moisture content is missing and invariance to change of  $\varepsilon$  isn't present.

 Table 2. Results of calculations of substance moisture content

Moisture	Calculated value of moisture content $(W_{calc})$			
content	for	for	for	for
(W)	$\epsilon = 2$	ε = 2,5	$\epsilon = 3$	$\epsilon = 3,5$
0	-0,0076	-0,0009	0,0057	0,013
0,1	0,013	0,02	0,027	0,034
0,2	0,022	0,029	0,036	0,044
0,3	0,018	0,026	0,034	0,042

Thus there is a need for creation of one more test with greater addition of water. In this case Eq. 3 will be:

$$\begin{cases} C_1 = \varepsilon (1+3W)g, \\ C_2' = \varepsilon (1+3(W+\Delta W'))g, \\ C_3' = k' \cdot \varepsilon (1+3W)g, \end{cases}$$
(10)

where:  $C_1$ ,  $C_2'$ ,  $C_3'$  – capacity of PMT with initial sample of substance and at creating of additive and multiplicative tests respectively, pF  $\Delta W'$  – addition of water for additive test, equal 0,2 (20 %); k' – coefficient for multiplicative test, equal 4.

As well as in the first case the system of Eq. 10 is solved using differential method. The calculated value of moisture content can be determined by a formula:

$$W_{calc2} = \frac{\Delta W'(C_3' - C_1)}{(k' - 1)(C_2' - C_1)} - \frac{1}{3}.$$
 (11)

Capacities of primary transducer can be determined by formulas:

$$C_1 = g \cdot \varepsilon_1, \qquad (12)$$

$$C_2' = g \cdot \varepsilon_2', \qquad (13)$$

$$C_3' = g \cdot \varepsilon_1 \cdot k', \qquad (14)$$

where:  $\varepsilon_2'$  – dielectric permeability of substance with addition of water  $\Delta W'$ , equal 0,2 (20 %).

Check on invariance the various combinations of two test expressions: Eq. 4 and Eq. 11. The most obvious combination is the ratio:

$$\frac{W_{calc2}}{W_{calc1}} = \frac{\frac{\Delta W'(C_3 - C_1)}{(k' - 1)(C_2' - C_1)}}{\frac{\Delta W(C_3 - C_1)}{(k - 1)(C_2 - C_1)}}.$$
(15)

Results of calculations of substance moisture content for Eq. 15 are given in Table 3.

 Table 3. Results of calculations of substance moisture content

Moisture	Calculated value of moisture content $(W_{calc})$			
content	for	for	for	for
(W)	$\epsilon = 2$	$\varepsilon = 2,5$	$\epsilon = 3$	$\varepsilon = 3,5$
0	0,898	0,899	0,902	0,903
0,1	0,885	0,889	0,891	0,894
0,2	0,872	0,874	0,877	0,88
0,3	0,852	0,857	0,861	0,865

As evident from results of calculations the invariance of moisture content  $W_{calc}$  to change of substance dielectric permeability still isn't present. Monotonous increase is present along with low sensitivity of PMT to change of moisture content.

Next, check on an invariance a combination of ratio of square of moisture content calculated value for test with an addition of water equal 20 % to a calculated value of moisture content of test with an addition of water equal 10 %.

$$\frac{W_{calc2}^{2}}{W_{calc1}} = \frac{\left(\frac{\Delta W'(C_{3}' - C_{1})}{(k' - 1)(C_{2}' - C_{1})}\right)^{2}}{\frac{\Delta W(C_{3} - C_{1})}{(k - 1)(C_{2} - C_{1})}},$$
 (16)

Results of calculations of substance moisture content are given in Table 4.

By the results of calculations of Table 4 it is visible that monotonous increase of values of moisture content is missing.

 Table 4. Results of calculations of substance moisture content

Moisture	Calculated value of moisture content ( $W_{calc}$ )			
content	for	for	for	for
(W)	$\epsilon = 2$	$\epsilon = 2,5$	$\epsilon = 3$	ε = 3,5
0	0,262	0,269	0,276	0,282
0,1	0,272	0,279	0,286	0,293
0,2	0,27	0,277	0,285	0,292
0,3	0,255	0,264	0,272	0,281

Check the combination on invariance:

$$\frac{W_{calc2} + W_{calc1}}{W_{calc2} - W_{calc1}} = \frac{\Delta W'(C_3' - C_1)}{(k' - 1)(C_2' - C_1)} + \frac{\Delta W(C_3 - C_1)}{(k - 1)(C_2 - C_1)}, \quad (17)$$

$$\frac{\Delta W'(C_3' - C_1)}{(k' - 1)(C_2' - C_1)} - \frac{\Delta W(C_3 - C_1)}{(k - 1)(C_2 - C_1)}$$

Results of calculations of substance moisture content are given in Table 5.

 Table 5. Results of calculations of substance moisture content

Moisture	Calculated value of moisture content ( $W_{calc}$ )			
content	for	for	for	for
(W)	$\epsilon = 2$	$\epsilon = 2,5$	$\epsilon = 3$	$\varepsilon = 3,5$
0	-18,543	-18,799	-19,342	-19,654
0,1	-16,467	-17,017	-17,338	-17,836
0,2	-14,606	-14,909	-15,315	-15,696
0,3	-12,504	-12,952	-13,353	-13,772

From the Table 4 it is visible that value W increases with increase of  $\varepsilon$ , therefore it is necessary to make a correction in a denominator of Eq. 17 for its more intensive increase with increase of  $\varepsilon$ .

Thus taking into account correction of the denominator we will receive:

$$\frac{W_{calc2} + W_{calc1}}{(W_{calc2} - W_{calc1}) \cdot (1 + 0,011 \cdot C_1)}.$$
 (18)

Results of calculations of substance moisture content are given in Table 6.

Apparently from results of calculations the deviation of moisture content calculated values still is significant.

Moisture	Calculated value of moisture content ( $W_{calc}$ )			
content	for	for	for	for
(W)	$\epsilon = 2$	$\epsilon = 2,5$	$\epsilon = 3$	$\epsilon = 3,5$
0	-15,199	-14,744	-14,543	-14,191
0,1	-12,789	-12,534	-12,147	-11,92
0,2	-10,657	-10,219	-9,906	-9,62
0,3	-8,478	-8,168	-7,884	-7,656

 Table 6. Results of calculations of substance moisture content

Further for the purpose of receiving an optimum denominator we will change the multiplier of  $C_1$  in Eq. 18 with some chosen step h. As a result of the analysis of received new combinations the expression for which the deviation of moisture content calculated values is minimum is determined. At the further change of the coefficient with specified step the deviation is increased. This expression is:

$$\frac{W_{calc2} + W_{calc1}}{(W_{calc2} - W_{calc1}) \cdot (1 + 0,0029 \cdot C_1)}.$$
 (19)

Results of calculations of substance moisture content are given in Table 7.

 Table 7. Results of calculations of substance moisture content

Moisture	Calculated value of moisture content $(W_{calc})$			
content	for	for	for	for
(W)	$\epsilon = 2$	$\epsilon = 2,5$	$\epsilon = 3$	$\epsilon = 3,5$
0	-17,526	-17,528	-17,794	-17,843
0,1	-15,306	-15,551	-15,582	-15,772
0,2	-13,306	-13,3	-13,388	-13,455
0,3	-11,112	-11,219	-11,288	-11,376

The results of calculations received for Eq. 19 have a minimum deviation and are monotonously increasing.

The values of moisture content received in Table 7 are nonnormalized. Normalization of values includes the following stages:

a) transformation of  $W_{calc}$  to positive values range:

$$W_{positve} = |W_{calc max}| + W_{calc}, \qquad (20)$$

where:  $|W_{calc max}|$  – maximum modulo value of moisture content for Table 7, equal 17,843,

b) combination of ranges:

$$W_{norm} = \frac{W_{positive}}{x}, \qquad (21)$$

where: 
$$x = \frac{6,624}{0,3} = 22,08$$

The normalized values are given in Table 8.

 Table 8. Normalized values of calculations results of substance moisture content

Moisture	Normalized values of calculations results of substance moisture content $(W_{norm})$			
(W)	for	for	for	for
(")	$\epsilon = 2$	$\varepsilon = 2,5$	$\epsilon = 3$	$\varepsilon = 3,5$
0	0,014	0,014	0,002	0
0,1	0,115	0,104	0,111	0,094
0,2	0,205	0,206	0,202	0,199
0,3	0,305	0,3	0,297	0,293

In order to compare the results of calculations given in Table 8 for Eq. 19 with the results obtained in early works [6, 21, 22] in this direction of research, we will apply Pearson's criterion of consent  $(\chi^2)$  [7]. This criterion allows accepting or rejecting of hypothesis about conformity of samples.

This criterion allows us to estimate degree of deviation of the calculated data from the ideal values of moisture content.

In [22] the least-squares method (LSM) was applied for creation of test influences system. Expression for determination of substance moisture content in this case is:

$$W_{calc} = \frac{100(0.17\varepsilon_1 + 0.17\varepsilon_3 - 0.33\varepsilon_2)}{\varepsilon_3 - 0.013\varepsilon_3^2}, \quad (22)$$

where:  $\varepsilon_1$  – dielectric permeability of initial sample of substance,  $\varepsilon_2$  – dielectric permeability of substance sample after addition of a known amount of water (the first test influence),  $\varepsilon_3$  – dielectric permeability obtained after addition to the second test still of the same amount of water (the second test influence).

Results of check of this expression are given in Table 9.

Moisture	Normalized values of calculations results of substance moisture content $(W_{norm})$			
(W)	for	for	for	for
(")	$\epsilon = 2$	$\varepsilon = 2,5$	$\epsilon = 3$	$\varepsilon = 3,5$
0	0,008	0,009	0,000	0,001
0,1	0,097	0,088	0,090	0,085
0,2	0,218	0,222	0,222	0,223
0,3	0,419	0,415	0,354	0,417

**Table 9.** Results of calculations of substance moisture content with application of LSM

In [6] Lagrange's interpolation polynomial of the second order was applied for obtaining value of moisture content. This polynomial is an interpolation dependence of moisture content of substance from its dielectric permeability.

The expression obtained with the use of second order polynomial is:

$$W_{calc} = 59,2 - \frac{10 \cdot \frac{\varepsilon_3 - \varepsilon_2}{\varepsilon_1 - \varepsilon_2} + 20 \cdot \frac{\varepsilon_3 - \varepsilon_1}{\varepsilon_2 - \varepsilon_1}}{100 - 90 \frac{\varepsilon_3 - \varepsilon_2}{\varepsilon_1 - \varepsilon_2} - 70 \frac{\varepsilon_3 - \varepsilon_1}{\varepsilon_2 - \varepsilon_1}}, \quad (23)$$

where:  $\varepsilon_1$  – dielectric permeability of initial sample of substance;  $\varepsilon_2$  – dielectric permeability of substance sample after addition of a known amount of water (the first test influence),  $\varepsilon_3$  – dielectric permeability obtained after addition to the second test still of the same amount of water (the second test influence).

Results of check of this expression are given in Table 10.

**Table 10.** Results of calculations of substance moisture content with application of Lagrange's polynomial of the second order

Moisture	Normalized values of calculations results of substance moisture content ( $W_{norm}$ )			
(W)	for	for	for	for
(")	$\epsilon = 2$	$\epsilon = 2,5$	$\epsilon = 3$	$\varepsilon = 3,5$
0	0,0	0,0	0,0	0,0
0,1	0,08	0,08	0,08	0,08
0,2	0,16	0,16	0,16	0,16
0,3	0,32	0,24	0,24	0,24

Checking the results of calculations on conformity by Pearson's criterion is carried out as follows.

Empirical value of Pearson's criterion can be determined by a formula:

$$\chi^{2}_{emp} = \sum_{i=1}^{m} \frac{(W_{norm} - W)^{2}}{W},$$
 (24)

where:  $W_{norm}$  – normalized value of moisture content (it is used as empirical value) W – specified moisture content of substance (it is used as theoretical).

So we will calculate empirical value of Pearson's criterion for results of Table 8. When true value of moisture content equals 0 it is visible that at various dielectric permittivities we will receive empirical values of moisture content 0,014; 0,014; 0,002 and 0 respectively; for 0,1 we will receive values of 0,115; 0.104 ; 0,111; 0,094, etc. Apparently not all results of calculations coincide with true values i.e. there are deviations. Taking into account all possible deviations for Table 8 we will receive:

$$\chi^{2} emp = \frac{(0,014-0)^{2}}{0,014} + \frac{(0,014-0)^{2}}{0,014} + \frac{(0,014-0)^{2}}{0,014} + \frac{(0,002-0)^{2}}{0,014} + \frac{(0,002-0)^{2}}{0,014} + \frac{(0,115-0,1)^{2}}{0,1} + \frac{(0,104-0,1)^{2}}{0,1} + \frac{(0,104-0,1)^{2}}{0,1} + \frac{(0,094-0,1)^{2}}{0,1} + \dots + \frac{(0,305-0,3)^{2}}{0,3} + \frac{(0,3-0,3)^{2}}{0,3} + \frac{(0,293-0,3)^{2}}{0,3} = 0,028.$$
(25)

Empirical values of Pearson's criterion for results of calculations with the use of LSM and Lagrange's polynomial of the second order are defined similarly.

Results of calculations of Pearson's criterion are given in Table 12.

**Table 12.** Results of calculations of Pearson's criterionfor table 8, LSM and with application of Lagrange'spolynomial of the second order

Indexes	$\chi^2 emp$
For Table 8	0,033
For LSM	0,171
For Lagrange's polynomial of the second order	0,085

#### CONCLUSIONS

1. Attempt to use test methods for solving the uncertainty of substance type problem for capacitive moistures have been carried out.

2. As a result of application of test approach the Eq. 4 allowing to define substance moisture without dielectric permeability (i.e. substance type) has been received.

3. For minimization of deviations of calculated values which are received with use of test method from the set values the Eq. 19 is defined.

4. Apparently from results of Table 8 for Eq. 19 the calculated values of moisture content along with high sensitivity to change of moisture content are adequately invariant to change of substance dielectric permeability.

5. During check of the results received in article on coherence by Pearson's criterion it was determined that these values have the smallest divergences (are conformed) in comparison with the results received in the previous works on this direction.

6. Thus the Eq. 19 can be used at measurement of moisture content of the substance that dielectric permeability is unknown.

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#### СИНТЕЗ ТЕСТОВЫХ ВОЗДЕЙСТВИЙ ДЛЯ ДИЭЛЬКОМЕТРИЧЕСКОГО ВЛАГОМЕРА, ИНВАРИАНТНЫХ К ИЗМЕНЕНИЮ СОРТА ВЕЩЕСТВА

#### Екатерина Голуб, Александр Заболотный, Николай Кошевой, Ирина Кириченко

Аннотация. В статье проводится исследование различных тестовых воздействий с целью обеспечения инвариантности диэлькометрических влагомеров к изменению сорта вещества. Проведён анализ способов уменьшения сортовой Выделено неопределённости. наиболее направление перспективное исследований тестовые методы. Выбран алгоритм тестового метода и структурная схема измерительной системы для аддитивного и мультипликативного тестов. В ходе расчётов получено выражение для определения влагосодержания вещества, инвариантное к изменению диэлектрической проницаемости. C целью апробации данного выражения получены результаты проверки зависимости влагосодержания от диэлектрической проницаемости. Для определения согласованности результатов применён критерий Пирсона. Установлено, что данные результаты достаточно хорошо компенсируют "сортовую неопределённость".

Ключевые слова: диэлькометрический влагомер, сортовая неопределённость, тестовый метод, аддитивный тест, мультипликативный тест.

# Modelling of rolling friction with sliding

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S u m m a r y. The article proposes a mathematical model of the process of rolling friction with slip at the point of contact with the rail wheels of the locomotive in the implementation of thrust.

K e y words. The friction force, the force of adhesion, the contact, the contact area, rolling friction, sliding friction.

# INTRODUCTION

A sliding friction and friction of rolling with sliding are the most widespread types of friction in a technique. So, for example a friction of rolling with sliding is in toothed and toothed-spiral transmissions or between wheels and rails [16].

An experimental investigation on the process of friction interaction between the wheels of a railway vehicle and rails was carried out by using many methods for different locomotives and conditions [11]. The results obtained allow the possibility to put forth common laws for the adhesion process as follows:

• the basis of adhesion is the force of external friction;

• realization of adhesion force is impossible without a slip of the wheel relative to the rail.

## RESULTS

The problem of interaction of a rolling stock and railway way concerns to number of the major in a transport science [2, 9, 18, 22, 23].

The urgency of the numerous researches devoted given problem, is caused by what from the processes occurring in contact of interaction of a wheel and a rail, safety and technical and economic parameters of a traction rolling stock of railways (speed of movement, the losses connected with overcoming of resistance to movement, deterioration of wheels, rails, etc.) depend [3, 27].

Long-term operation of a rolling stock shows, that the resource of bandages of wheel pairs is defined by hire and, in a greater measure, deterioration of crests. The numerous publications testify to it, devoted to above permitted standard wear process of crests of wheel pairs and a lateral surface of a head of a rail. So, for example in [1] diagrams of structure of turnings of wheel pairs on operational park of locomotives on a network of railways of the Russian Federation 2012 which Analysis are presented shows, that made turnings of bandages of wheel pairs on admissible size of hire make 4 % while on deterioration of a crest their value reaches 65%.

With the purpose of decrease in intensity of wear process of wheel pairs and rails up to comprehensible values last years a number of actions of technical and organizationaltechnological character [8] (lubrication, improvement of a design of a way and locomotive servicing of a rolling stock, perfection of geometry of a structure of a surface of driving of wheels and rails, monitoring in system a wheel – a rail, etc.) is spent. From all listed directions of works most quickly introduction in a zone of contact of the third body with the set characteristics is sold.

The choice of the materials applied to cooling and greasing of contacting surfaces of crests of wheel pairs and rails, should be carried out in view of temperature conditions of interaction of the considered pair friction. How the temperature developing at friction, causes heating thin superficial layers of the interfaced bodies and a layer of greasing dividing them, it is one of the most important factors influencing all complex of service properties of lubricants, defining their antifriction properties.

During friction of a lateral surface of a crest of a wheel about a rail depending on loading, high-speed and temperature modes various modes of friction are realized: dry, boundary and полужидкого friction.

Change of modes of friction including formation of the mixed greasing, can be considered on diagram Hersy (fig. 1), showing dependence of factor of friction on the characteristic of a mode of greasing [25]. The dimensionless size is defined under the equation:

$$\lambda = \frac{\mu \cdot V}{P} \text{ or } \lambda = \frac{\mu \cdot \omega}{p},$$
 (1)

key parameters enter into it defining a mode of friction (viscosity of oil, speed, loading).

This curve has two characteristic branches: left, falling for area of boundary greasing and right, increasing, for area of liquid greasing. Between them there is the transitive site corresponding area semi fluid greasing (area). At transition in area unstable semi fluid greasing change of any parameter promoting decrease  $\lambda$  (reduction of viscosity, increase in loading, increase in speed of sliding), leads to increase of factor of friction and working temperature tribosystem. Growth of factor of friction in the given area occurs due to increase of a share of boundary greasing down to formation cleanly boundary greasing (area).



Fig. 1. Diagram Hersy

Modeling of thermal processes in pair friction a crest of a wheel-rail definition of power and geometrical conditions контактирования is carried out according to with described in [4] sequence.

At interaction of a crest of a wheel with a lateral surface of a head of a rail at presence between them a lubricant the factor of boundary friction can be calculated under the formula resulted in work [8]:

$$f_{mz} = f_{mp} - k \frac{\eta_{CM} \cdot v_{CK}}{P_{noz}}, \qquad (2)$$

where:  $f_{mp}$ - factor of friction of not greased surfaces,  $\eta_{cM}$ -dynamic viscosity of oil,  $v_{cK}$ -speed of sliding,  $P_{noe}$ - running loading, k-factor of proportionality. Modeling modes of friction considered tribosystem it is necessary to mean, that at dry friction the second member of the equation (1) can not be considered. The second part of the equation (1) generally is function of the characteristic of a mode of greasing. From the equation (1) it is visible, that three factors influencing a mode of greasing are speed, loading and viscosity of oil.

The factor of friction  $f_{me}$  depends, from actual (working) viscosity of greasing at temperature T on a surface of contact, instead of from the rating value defined in вискозиметре at conditional temperature and atmospheric pressure.

For the calculation of temperature on the surfaces of wheel and rail, it is necessary to define a form and size of spot of contact. We will represent the touch of wheel and rail, as a contact of cylinder with toroid with perpendicular axes. Sizes of spot of contact of wheel and rail is possible to define on the equations of theory of elasticity [24]:

$$a = 1.397n_a \cdot \sqrt[3]{\frac{P_\kappa}{E} \cdot \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} - \frac{1}{R_4}},$$
 (3)

$$b = 1.397n_b \cdot \sqrt[3]{\frac{P_{\kappa}}{E} \cdot \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} - \frac{1}{R_4}}, \quad (4)$$

where:  $n_a$ ,  $n_b$  - coefficients values of which are determined on tables; R1, R2, R3, R4 - radiuses of curvature of contacting bodies, E - the elastic module.

Change of temperature on the surface of friction of wheel flange with the head of rail in time, it is possible to define, deciding the unstationary task of heat conductivity which, in the case of independence of thermo physical properties of materials of contacting bodies from a temperature, is described by differential equalization of heat conductivity, which has a kind [31]:

$$\lambda \left( \frac{\partial^2 T}{\partial i^2} + \frac{\partial^2 T}{\partial j^2} + \frac{\partial^2 T}{\partial k^2} \right) \pm q = c_p \frac{\partial T}{\partial t}, \quad (5)$$

where:  $\lambda$  - coefficient of heat conductivity,  $c_p$  - heat capacity of materials by volume, q - thermal thread through a surface, T - temperature; t - time.

Normal loading P(x,y) we will define as work of pressure in every cell of spot of contact on the area of cells:

$$P(x,y) = \sigma(x,y) \cdot F.$$
 (6)

For determination of pressure  $\sigma(x, y)$  in every point of contact ground the equation of cycle per a second was used:

$$\sigma(x,y) = q_{\max} \sqrt{1 - \left(\frac{x}{a}\right)^2 - \left(\frac{y}{b}\right)^2}, \qquad (7)$$

where:  $\sigma_{max}$  - maximal value of pressure in the center of spot of contact. At the accepted chart of contact of wheel flange with the lateral surface of head of rail, value of maximal pressure, it is possible to define on the equation (8):

$$\sigma_{\max} = 0.245 \cdot n_p \cdot \sqrt[3]{P_{\kappa} \cdot E^2 \cdot \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} - \frac{1}{R_4}\right)^2}, \quad (8)$$

where:  $n_p$  - coefficient, the value of which is determined on tables [26].

Viscosity of all drop liquids and their mixes with rise in temperature decreases. For recalculation of viscosity from one temperature on another the equation (9) is recommended:

$$\eta_T = \eta_u \cdot \left(\frac{t_u}{t_T}\right)^n,\tag{9}$$

where:  $\eta_T$  – required viscosity of oil at temperature  $t_T$ ,  $\eta_u$  – Resulted in tables of GOST viscosity (in Nsm/m<sup>2</sup>) at temperature of test of oil,  $t_u$  – Temperature of test of oil on definition of its viscosity,  $t_T$  – temperature for which count viscosity, n - factor - an exponent for each grade of oil. Value of factor can be accepted under tables [23].

Results of calculation of parameters considered tribosystem at presence between them a lubricant are presented on fig. 2-5.



**Fig. 2.** Dependence of the attitude  $f_{mz}/f_{mp}$  from size of lateral force in contact of a crest of a wheel to a lateral surface of a rail ( $f_{mp}$  and  $f_{mz}$  – factor of friction of not greased surfaces and at boundary friction)



**Fig. 3.** Dependences maximal (a curve 1) and average (a curve 2) relative temperature in contact of a crest of a wheel to a lateral surface of a rail from size of lateral force (*Tsm.max/Tmax* - curve 1, *Tm.cm./Tm.* - curve 2)

Proceeding from data of calculation of temperature on a spot of contact at presence of a lubricant layer the processes proceeding on a surface of friction, it is possible to present in a following kind. So, at constant speed of sliding and accruing loading there is a gradual increase in intensity of allocation of heat of friction fig. 3 and, hence, rise in temperature of a layer of the oil dividing rubbing surfaces. Apparently from fig. 2, in a zone of force of interaction of contacting bodies 3 ... 25 kN



**Fig. 4.** A field of temperatures (t, °C) on a surface of contact of a crest of a wheel with a rail at presence between them greasings MC-20, (speed of movement Vline=60km/h, sliding  $\doteq 10\%$ , P=65kN)

there is an excess. It is possible to explain presence of an excess change of a physical and chemical condition of greasing due to a thermal emission in contact. To the further growth of temperature leads to that the oil layer loses protective properties and factor of friction becomes same, as for not greased surfaces.



**Fig. 5.** Dependence of the attitude capacities of friction in contact of a crest of a wheel to a lateral surface of a rail at presence of greasing and without it from size of directing energies.

The similar result is received in works [20] where the spasmodic increase in factor of a sliding friction was observed at rise in temperature in a zone of contact due to relative friction.

By means of the given calculation it is possible to estimate possible temperature in contact of interface under the heaviest conditions of its work and to pick up a lubricant with demanded operational properties.

For an estimation of influence applied at lubrication materials on conditions контактирования in considered a feather of friction we shall take advantage of power criterion of deterioration [9, 10]. Quality standard of deterioration we shall make calculation of capacity of forces of friction in a zone of contact for a series of oils, according to the described calculation.

Results of calculation of capacity of force of friction on a surface of contact of a crest of a wheel with a rail at presence between them greasing MC-20, (speed of movement Vline=60km/h, sliding  $\epsilon = 10\%$ , P=65kN are shown on fig. 5.

#### CONCLUSIONS

1. The analysis of the received results shows, that the effect from drawing greasing on rubbing surfaces is observed at rather small values of directing energies up to 10kN. In these conditions rather insignificant deterioration is observed.

2. Decrease in intensity of deterioration and a temperature mode with growth of value of directing energies can be reached at the viscosity of oil corresponding to temperatures considerably smaller than settlement temperature in a zone of friction.

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#### МОДЕЛИРОВАНИЕ ПРОЦЕССА ТРЕНИЯ КАЧЕНИЯ СО СКОЛЬЖЕНИЕМ

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Аннотация. В работе предложена математическая модель процесса трения качения с проскальзыванием в точке контакта колеса локомотива с рельсом при реализации силы тяги. Ключевые слова: сила трения, сила сцепления, контакт, площадь контакта, трение качения, трение скольжения.

# Study dynamics machining centre SF68VF4

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S u m m a r y. Procedure of the calculation forms for vibration of the carrier system machining centre milling-drill-bore types in condition low frequencies is realized. The organized categorization of main nodes and their presentation in the manner of rods and masses. 3D-model spindle's node is built in system KOMPAS-3D. Main nodes "spindle-instrument" and "tableworkpiece", exert most influence upon dynamic quality tool is exposure. Accounting scheme of the springy system tool is built and is offered mathematical description of the tasks dynamics with provision for characteristic of the process by cutting. They are determined transmission functions of the equivalent springy system tool and is designed its structured scheme.

K e y w o r d s: machining centre, dynamic characteristics, form of vibration, carrier system, spindle.

### INTRODUCTION

The Modern machine-building production puts before tool industries problems of increasing to accuracy and well capacity metalcuting tool, as as requirements on minimization of their cost [1, 19, 2]. This brings about need of searching for new and improvements existing design tool, to need of the use scientifically motivated methods of the designing, founded on mathematical modeling of the different processes, occurring in tool, providing possibility of the estimation to accuracy tool and influences upon it separate nodes on initial

stages of the designing already. Using of such methods accelerates the process of the development of the project, provides the possibility to optimization to designs and brings about significant reduction of the expenses on creation and complete of the pilot models.

Increasing of the requirements to quality milling tool, their technological complex in connection with the general increasing of accuracy in machine building, fabrication of the details from machining material, rational use high effective cutting instrument, compels to search for the way of the improvement main form creative nodes, ", exert most influence upon capacity and accuracy of the processing. These are a main technological features metal cutting equipment are limited, as a rule, their vibration resistance, for estimation which necessary knowledge of the dynamic features milling tool and its main element.

Besides, increase to efficiency of the processes realized on modern technological complex on the base multioperation equipment is connected with increasing of dynamic stability of the main nodes metal cutting tool. The analysis of the balance to softness and the forms of the frequencies form creative nodes multioperation tool milling-drill-bore type has shown that the most intensive frequencies are characterized such form creative nodes, as "spindle - mandrel - instrument" and "table - workpiece".

Such operations with interrupt by cutting as milling are characterized by big range power influence, appearing in process of the processing, including probabilistic forming in the manner of collections of the dynamic harmonicas.

# PUBLICATION AND METHOD ANALYSIS

In background labour on dynamic tool [15] is for the first time entered system of the factors dynamic quality tool (the spare and degree to stability, speed and deflection dynamic system parameter under external influence) and is given general methods theoretical and experimental analysis and estimations tool on this factor. The position is entered about closed loop of the dynamic system tool, which is defined interaction element springy system "tool-instrumentalequipment-detail" with workers process: cuttings, friction and in drive. Together with that, author limits the variety a quotient particularities of the dynamic phenomena's in tool, linearization system. These restrictions are justified by possibility of the analysis of the much of machine exhibits with sufficient for practical by accuracy result. The analysis of the particularities of the dynamic system tool enabled to enter the new notion "equivalent springy system" (ESS) metal cutting tool. It is directly connected with division of the zones, where run the worker processes element of the springy system. Such approach turned out to be efficient at decision of the following problems:

1. The problems connected with choice of the drive or its calculation, when as equivalent is considered element "mechanical system", including processes of the cutting and friction with their relationship.

2. The problems of the analysis of the conditions of friction in directing or bearing of the nodes tool. Here, the equivalent element unites the springy system and processes in engine.

3. The problems of the calculation of the conditions of the cutting, where as equivalent element are considered springy system tool and processes in engine and friction.

The approach offered prof. V.A. Kudinov turned out to be productive in different exhibits tool building to branches. So in work [17] is considered dynamics mechanism auxiliary motion, in particular mechanism of the periodic turning of the nodes (the geneva, cam-teat, toothed-arm and slotted link mechanisms). It besides is in detail considered dynamics clamping and load mechanism, including intended for automatic change the instrument.

In work [18] is conducted study ESS special diamond-bore tool and are defined frequency features boring bar diamond-bore of the heads and for improvement dynamic quality are offered designs of the dumper vibration of the frequencies. For these design is built model, on the base which are built amplitude-phase-frequency characteristics springy system "spindle-console" with damper of the frequency. On the base result, got in are determined dynamic work [15] characteristics of the process fine bore, moreover determination of constant time chip formation  $T_r$  and specific power of the cutting K<sub>r</sub> is realized on base built nomograph that relieves the calculations of the features of the process of the cutting.

Together with that got in work [15, 18] dynamic characteristic of the process of the cutting, got as a result direct experiment, needs event overflow for revision. For chip formation revision is connected with presentation of the process to deforming the chip, moving on cutter as on beam on soft base [8]. On the grounds of found dependencies of the length of the contact of the chip and transmission instrument are received functions, characterizing change the length of the contact when change the thickness of the cut. Comparing got results with available experimental given possible to note their qualitative coincidence [8].

At a rate of configuration designing is offered as criterion of the comparison of the arrangements to use not generalized criterion, but factor dynamic quality on limiting operation [9, 4]. On the base experiment on lathes is shown, [9] that under firm cutting level frequency in zone of the cutting the most intensive in low frequency of the area, corresponding to own frequency of the vibration of the carrier system (CS) tool. In this dynamic characteristic case CS computable under chosen accounting condition, will characterize the quality of the arrangement with position to not only stability of the process, but also influences of the vibration on accuracy of the processing. The similar approach is used for comparison of the arrangements multi-objective tool millingdrill-bore type [4, 10]. The organized collation of the dynamic characteristic CS different arrangements, differing mutual location stationary and moving block, in particular, location tool magazine and spindle head on column. As criterion for comparison was used factor to dynamic softness. Volume of dynamic softness is calculated for different technological operation on the first and second own frequency under different design spindle head. On this base is made choice to rational design element carrier systems.

Final element method is broadly used at study dynamic multi-objective tool. So in work [11, 5] is presented complex approach to problem of the multiversion analysis of the dynamic characteristics of the springy systems tool, resting in their schematizing by means of super element, uniting between itself in border node point final-element grid. The certain balance to dynamic softness multi-objective tool with crusade table [11, 12]. For detail of the influence constructive parameter on its dynamic characteristic is used procedure of the energy analysis of the vibration spring system on determined mode of the vibration on frequency 41 and 66 Hz. The results of the analysis have allowed to give the recommendations on change design element spring system tool in purpose of the improvement its dynamic characteristic.

The influence upon dynamic quality multi-objective tool with use hydraulic motor drive is considered in work [21, 22].

The analysis dynamic quality tool for speediest processing (the parameter specific speed  $n \cdot d = (2...3) \ 10^6 \text{ mm/min}$  is connected monitoring spindle's nodes with on characteristic of the displacement and vibration [1]. For checking and forecasting of the nature and values vibration in process of the processing are created special programs, taking into account condition spindle's nodes and instrument, material of the workpiece, stiffness of its fastening and other characteristics.

# **OBJECTS AND PROBLEMS**

The purpose of the work is an improvement of the process of the designing main form creative nodes machining centre on the base of the procedures of the study dynamic and shaping rational design these tool on criterion vibration resistant

# THE MAIN SECTION

Considering design multi operation tool, as closed-loop dynamic system [15, 18, 17], most often resort to schematizing, got in work V.A. Kudinov [15].

In general event equivalent springy system tool (ESS) tool milling-drill-bore type can be presented in the manner of linear system with many degrees of freedom. The system includes certain amount concentrated and portioned element, possessing corresponding to inertia, springy and dissipation characteristics.

During preliminary experiment on base model tool SF68VF4, constructed and made on Lugansk tool building plant, are received: moving the instrument and workpiece, installed on rotary table under the action of weight of the elements and power  $P_{x,y,z}$ . Herewith, the most disadvantage scheme of the location for elements of the carrier system tool was taken into account (Fig.1) – a spindle in the most extreme position; the table with workpiece in the most lower position.



**Fig. 1.** The Schemes of the location of the elements tool: a - a scheme I, b - a scheme II

For estimation of the influence parameter form created elements on level of dynamic softness necessary building forms of the vibration on that own frequency, which are characterized comparatively high level of the fluctuations of the instrument and stocking up. The Analysis experimental amplitudefrequency characteristics have shown that most interest presents the low frequency of the vibration fi (Hz):

 $fi = \{ 16,5; 20,2; 24,6; 28,6; 44,2 \}.$ 

On specified above frequency were calculated forms of the vibration of the carrier system tool, and the numerical values of the displacement their element. On Fig.2 graphic are presented forms of the vibration on frequency f = 20,2 Hz, which are characterized intensive displacement spindle head in planes XOZ and table with workpiece in planes YOZ. Herewith springy deformation were fixed under the most disadvantage scheme of the location of the elements tool (Fig.1, scheme 1)

and following variant load:  $P_{z1}$ = -1000 H;  $P_{y1}$ = $P_{x1}$ = 1000 H (are attached on the end of the spindle).



Fig. 2. Form of the vibration tool on frequency f = 20,2 Hz

On base of the picture of the displacement point springy system tool is organized categorization its main elements: arrays and rods (the springy beams). The pertain to array – instrument, table rotary, workpiece and drives of the presenting and the main of the motion (Tabl.1).

Table 1. Categorization for main elements of tool

Indication	Node tool	
(number of the node)	Node tool	
Concentra	ated masses (arrays)	
1	Instrument	
9	Drives main motion	
14	Drive of feed (on axis Y)	
16	Table rotary	
17	Workpiece	
	Rods	
2-3-4	Spindle's node	
5-6-7-8	Splinde's head	
10-11-12	Column	
14-13-15	Carriage	
	Joint	
2-5, 3-6	Support of spindle's node	
7-9, 8-9	Support of engine	
7-10	Splinde's head - column	
11-13	Column - carriage	
14-16	Carriage - vertical table	
16-17	Table rotary - detail	
Supports		
12-0	Base- foundation	



Fig. 3. Accounting scheme tool

As is well known, under array are understood such elements tool, own deformation which possible neglect in contrast with contact deformation in their butting with the other element that affords ground present them in the manner of concentrated masses (Fig.3) [5].In joint "table rotary- detail" will be taken into account only angular softness in plane YOZ and YOX.

The spindle tool, which 3D-model is designed in CAD KOMPAS-3D [13, 14, 3] (Fig.4) is submitted for accounting scheme in the manner of weightless springy beam with three concentrated masses on two elasticity damper supports. Instrument it if its own deformation possible to neglect (stiffness boring bar, milling cutter) introduces the array.

Thereby, real springy system tool is replaced by accounting scheme i.e. system with final number of the degrees of freedom in the manner of 5 concentrated masses, united springy and dissipation (diffusing energy of the vibration) element, with linear characteristics usually.



Fig. 4. Spindle's node: a – assembly, b – mating parts

Each mass in general event can have six degrees of freedom and its motion must be described six times by differential equations of the second order.

The reduction to working hours of the exact calculation of the system is connected with highlighting of the main elements, rendering most influence upon level of the factors dynamic quality. The concrete variant of the highlighting depends from delivered tasks in turn. So in task of the analysis and estimations to accuracy designed tool in process of the operation (form creative surfaces of the details) solving importance renders spindle's element [20]. This is confirmed by broughted studies with using the spectral analysis, which have shown that in roundnessgramm of the surfaces of the processed details are present only frequencies typical of vibration spindle's element i.e. frequency spectrum of the vibration to paths to axis of the spindle is wholly copied on detail.

Together with that other form creative element tool on the base SF68F4 in the general picture deformation conditions greatly influences upon quality produced to product:

- on frequency of the vibration f = 16,5 Hz exist the intensive fluctuations of the table rotary and carriage toward axises X and Y, that brings about torsion of the body carriage and deformation in joint "column- carriage ", " carriage -table",

- on frequency f = 20,2 Hz occur the rocking vibration carriage with table for column in planes YOZ, which are defined by angular stiffness of the joint guideway column with carriage in planes YOZ with total mass of the workpiece the table and carriage (Fig. 2),

- on frequency f=28,6 Hz also exist the intensive vibration an spindle's head and table rotary in planes YOZ.

Though springy systems tool with NC type SF68VF4 present itself multimass connectivity system, breach of the form and quality processed surfaces depends, first of all, from such main and form creative elements as "Spindle-instrument" (S-I) and "Tableworkpiece"(T-V). Thence possible draw a conclusion that considered springy system tool with satisfactory approach possible to consider as two mass. This is confirmed and constancy of the amplitude of the springy moment under undermost form of the vibration.

The relative small size of the amplitudes of the vibration (Fig. 1), presence preload springy system, created power of the cutting and weight of its element and applicability of the principle superposition (within the range of acting indignations) allows to consider this system linear, described by system of the common differential equations of the second order.

For machine centre to models SF68F4 accounting scheme of the equivalent springy system (the Fig. 5) includes two concentrated masses  $m_1$  (the subsystem "S-I") and  $m_2$  (the subsystem "T-W"), having linear characteristics to stiffness  $K_1$  and  $K_2$  and damping  $h_1$  and  $h_2$ .



**Fig. 5.** Accounting scheme of the equivalent springy system:  $m_1 - a$  concentrated mass of the subsystem S-I,  $m_2 - a$  concentrated mass of the subsystem T-W,  $h_1$  and  $h_2 - damping$  factor

The Mutual influence of the masses  $m_1$ and  $m_2$  occurs in process of the cutting with stiffness factor of the cutting Kr [15]. Under such statement of the problem instrument and workpiece are bound with each other by process of the cutting.

The Mutual influence of the masses m1 and m2 occurs in process of the cutting with stiffness factor of the cutting k. Such two mass system can be described by system of the differential equations of the second order with practically constant factor i.e. vibration section:

$$\begin{split} & m_1 \dot{y}_1 + h_1 \dot{y}_1 + k_1 y_1 - k(y_2 - y_1) = 0; \\ & m_2 \dot{y}_2 + h_2 \dot{y}_2 + k_2 y_2 - k(y_2 - y_1) = F_0, \end{split}$$

where:  $y_1 - a$  moving the subsystem S-I,  $y_2 - a$  moving the subsystem T-W,

 $F_0$  – outraging power, appearing in consequence of instability of the spindle and mandrels, as well as unevenness allowance.

For account dynamic property necessary to take into account the dynamic characteristic of the process of the cutting [15]; as inertia link first-order:

$$T_{p} \mathbf{F}_{p} + \mathbf{F}_{p} = \mathbf{K}_{p} \mathbf{y}, \tag{2}$$

where:  $K_p=K_3$  b=(1,3...1,5)  $\sigma_{F} \cdot b$  - stiffness of the cutting,

 $K_3$  – specific power of the cutting, N/mm,

b – width of the chip, mm,

 $\sigma_B$  – a temporary resistance of the processed material, MPa,

 $F_p$  – power of the cutting (brought about normal coordinate), N.

Constant time chipcreating  $T_r$  is defined by dependency:

$$T_{p} = \frac{\alpha a_{2}^{2}}{w},$$

where:  $\alpha$  – a factor to proportions,

a – thickness of the chip, mm,

V - a velocity, m/s,

 $\xi$  – factor of the chip contraction.

Considering expression for averaged stiffness S-I and equation (1) to account of the expression (2) is realized building of the system integral-differential equations:

$$\begin{split} & m_{4}\dot{y}_{4} + h_{4}\dot{y}_{4} + k_{4}y_{1} - F_{p} = 0, \\ & m_{2}\dot{y}_{2} + h_{2}\dot{y}_{2} + k_{2}y_{2} + F_{p} = F_{0}, \\ & T_{p}F_{p} + F_{p} = K_{p}(y_{2} - y_{2}). \end{split}$$

The presentation (3) correct for event, when velocities of the longitude feeds presenting comparatively small in contrast with value of the transverse vibration S-I.

In operation form (using transformations Laplas: p = d/dt, system (3) possible present in the manner of:

$$\begin{split} (m_1 p^2 + h_1 p + k_1) y_1 &- \frac{\kappa_p}{\tau_p p^{s+1}} (y_2 - y_1) = 0, \\ (m_1 p^2 + h_1 p + k_2) y_2 &- \frac{\kappa_p}{\tau_p p^{s+1}} (y_2 - y_3) = F_0(p). \end{split}$$

After transformations we shall get the transmission function W(p) on outraging influence  $F_0(p)$ :

$$W(p) = \frac{Z(p)}{F_{0}(p)} = \frac{A(p)(T_{p}p+1)}{K_{p}[A(p)+B(p)]+(T_{p}p+1)A(p)B(p)]}$$
(5)

where: Z(p) - an output parameter of the system:

$$\begin{split} Z(p) &= y_2(p) - y_4(p), \\ A(p) &= m_4 p^2 + h_1 p + k_4, \\ B(p) &= m_2 p^2 + h_2 p + k_2. \end{split}$$

Relative moving the masses "S-I" and "T-W" is an algebraic amount:  $Z = y_2 - y_1$ moreover moving the detail  $y_2$  includes two forming:

 $y_2'$  – is caused influence outraging power  $F_0$ ,

 $y_2$ " – is caused influence springy link "S-I".

On base of the foregoing interpretation structured scheme dynamic system tool can be presented in the manner of:



Fig. 6. Structured scheme of the dynamic system tool

On fig. 6 are presented transmission functions  $W_1(p)$ ,  $W_2(p)$  and  $W_3(p)$ , reflecting transformations: outraging power  $F_0$  in forming moving the spindle  $W_1(p)$ , resulting moving the workpiece in displacement 3BeHa "S-I"  $W_2(p)$ , expressing influence of the process of the cutting and resulting displacement springy link "S-I" in the second forming moving the workpiece  $W_3(p)$ reflecting speaker 3BeHa "T-W".

Transmission function in operating form for tool as a whole can be presented as:

$$W(p) = \frac{W_1(p)[1 - W_2(p)]}{1 - W_2(p)W_2(p)}.$$

#### CONCLUSIONS

1. In given article is presented procedure of the study dynamic machining centre with table rotary.

2. The experimental analysis amplitudefrequency characteristics of the equivalent springy system (ESS) tool to models SF68VF4 that has allowed to reveal the spectrum an low frequency, under which exists the high level a vibration instrument and workpiece is carry out.

3. The calculated form of the vibration of the carrier system tool, on base which is organized categorization of the main elements and presentation them in the manner of rods and array.

4. 3D-models of the separate details and assemblies spindle's element in CAD KOMPAS-3D is built. This is a base of the further modeling.

5. Information ESS is restore to two mass vibration system on the base two the most affecting vibration link: "tableworkpiece" and "spindle-instrument".

6. Accounting scheme ESS is built and is offered description in the manner of systems of the differential equations two order with constant coefficients.

7. Transmission functions ESS tool SF68VF4 are received in operation form and is designed structured scheme of the dynamic system tool.

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#### ИССЛЕДОВАНИЕ ДИНАМИКИ МНОГООПЕРАЦИОННОГО СТАНКА СФ68ВФ4

#### Олег Кроль, Максим Бельков

Аннотация. Рассчитаны и построены формы колебаний несущей системы обрабатывающего центра фрезерно-сверлильно-расточного типа в условиях низкочастотных вибраций. Проведена классификация основных узлов и их представления в виде стержней и масс. Построена 3D-модель шпиндельного узла в системе КОМПАС-3D. Выявлены основные узлы"шпиндель-инструмент" и "стол-заготовка", которые оказывают наибольшее влияние на динамическое качества станка.

Построена расчетная схема упругой системы станка и предложено математическое описание задачи динамики с учетом динамической характеристики процесса резания. Определены передаточные функции эквивалентной упругой системы и разработана структурная схема станка.

Ключевые слова: Обрабатывающий центр, динамическая характеристика, формы колебаний, несущая система, шпиндель.

# Increase accuracy of system operation of unloading heavy coal sinks and middlings in jigs

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S u m m a r y : The article presents a study on improving the accuracy work of measurement and adjustment of the height of the coal bed - one of the most important process parameters of coal cleaning in jigs. Were identified shortcomings of existing sensors. Were worked out the ways of improving these measuring devices. In article proposed a method to perform a qualitative assessment for the control system of accuracy of unloading heavy sinks and middlings in jigs.

Key words: Jigging, coal bed, yield of fractions, density, lifting force.

## INTRODUCTION

Method of hydraulic jigging of coal continues to be one of the most common methods of preparation of fine coal during recent decades. The total mass of fine coal reprocessing enriched by jigging is very impressive and makes up dozens of millions of tons despite a decline in the trend of reprocessing this type of coal in the early 2000's. But the quality of the processed product does not always satisfy consumers of coal [11].

In such a situation any appreciable increase in the yield of useful products enrichment and improvement of their quality is a significant contribution to improving the efficiency of the coal industry of the country. Such positive changes can be achieved only by improving the properties of automatic control systems (ACS) of coal bed regulation in jiggers.

In this regard the issue of increase the accuracy of unloading heavy sinks and middlings in jigs is an urgent task.

# MATERIALS AND METHODS

Analysis of characteristics of technological equipment for the implementation of the process of jigging [1, 6, 8, 26] shows that the main characteristics of jigs ACS have been significantly improved over the last 20-30 years [12, 14,15].

In particular, have been developed and proposed for industrial use blocks of forced oscillations BVK (for the best choice of airwater cycle), have been developed various fuzzy controllers, corrective function blocks for the systems unloading heavy products of enrichment, appeared device for analyzing and forecasting of process results [3, 7, 10, 23]. However, the available information does confirm fact significant not the of improvement of products of jigging [24, 29, 30].

In this article, the authors set out to identify the main reason that prevents the growth of ACS efficiency of the process of coal beneficiation process in jigs and suggest ways to improve these systems.

At the first stage let's try to find the "weak link", which is one of the main reasons hindering for achievement the high quality products of coal enrichment in jigs.

At first let's analyze the control system of water-air regime of jigging machine.

In the works of N.Vinogradov, N.Shmachkov and E.Rafales Lamarcka [13, 17, 18, 22, 31] were shown that the speed of the rising stream of coal-water mixture during rippling determined the level of exfoliation of coal bed.

For quantifying the degree of exfoliation of the coal bed by fractions E. Rafales Lamarcka proposed criterion R, numerically equal to the expression:

$$R \cong n \int_{\text{cycle}} S \, dt, \tag{1}$$

where: R – loosening criterion, cm•c/min,

n - the number of oscillations of coalwater medium in 1 min,

S – moving of the upper layers of bed in a vertical direction, cm.

Subsequently in research work K.Vlasov and L.Lehtsier [32] were suggested to assess the value of loosening criterion R using a value S of lifting of certain layer of coal bed. Also was suggested to assess the value of loosening criterion R as the time of staying certain layer of coal bed in a movable state. Thus after some transformations the expression (1) considering the above notation can be converted to the form:

$$R = \frac{2}{\pi} * \frac{t_s}{T} * S_{\text{max}}.$$
 (2)

From expression (2) we can see that in the first place the coal bed looseness is proportional to the relative duration of the moving condition of the coal bed and in the second place the coal bed looseness is proportional to the peak-to-peak value of height coal bed.

We'll note that numerous attempts to put into practice the conclusions that follow from the expression (2) do not allow fully getting a positive effect. Obstacle to the achievement of positive results was the difficulty of measuring the parameters  $t_s$  and  $S_{max}$ . This is explained by the following circumstances. Source of information for determining the value of loosening coal bed R is prismatic float sensor in all constructions of jiggers. The height of the float sensor to ensure stable movement in a coal-water mixture usually is chooses commensurate with the total height of the coal bed.

Significant part of the float sensor in the majority of jiggers is above the coal bed, and often overtop at 10-30 cm above the transport water. The lower part of float is usually located at a distance of 5-10 cm from the sieve of jigger. A typical form of such a sensor is shown in the figure below, which was taken from the work about coal preparation in jiggers [19]



Fig. 1. Unloader of jig Humboldt and BATAC: 1 - float, 2 - counterweights, 3-7 - levers

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Adjusting the position of the float sensor in the coal bed realized by the operator of jigger. Adjustment is made usually by plant or by removal the certain weight on the float or in a particular location of the lever system.

The exact method of determining the mass of loads for necessary adjustment does not exist, because there are no criterions for the accuracy testing of the settings. Jigs operators are trying to reconfigure float density when parameters of initial coal are changing. We can observe the similar situation looking at work of the system unloading heavy products of jigger enrichment.

#### **RESULTS, DISCUSSION**

Analyzing the mechanism and operation of various types of jiggers machines can be concluded that unloading process of heavy coal fractions depends only from the position of the float sensor regardless of the design of all jiggers.

The principle of process control by discharge is clear and simple: all the heavy fraction of the exfoliated coal bed located below the level of a certain fraction, you must discard (if this is the first or second branch of jigger during the incoming coal) or you must send it to a middling (if this is the last or penultimate branch of jigger). Coal-cleaning workers chosen usually medium density coal fraction 1,5-1,8 g/cm<sup>3</sup> as a certain coal fraction in separating zone which detaches the concentrate from rock. Let's note that just as in the case of automatic control system of waterinformation air cycle, for controlling unloading process heavy products goes from the same float sensor of coal bed height.

We have not discovered in published works research on the measurement accuracy of bed height with given density using the float sensor. Taking into account the above design features of float sensor, there is reason to assume that the signal carrying information about the height of a measurable layer bed can hardly be considered to be proportional to the true value of this height.

In considering this issue should be aware that the precise definition of a apparent coalwater mixture density is a complex task requiring the simultaneous use of hydrodynamic and probabilistic calculation methods, as well as accounting of the dimensions data of the float sensor and the jigger. In this connection, let's perform the assessment of the accuracy of measurement of height layer bed by approximate way for the purpose to obtain a qualitative picture of the of the results dependence of height measurement from the fractional composition of coal bed.

To simplify the problem, let's represent the float in the form of a right prism with the cross-sectional area equal to  $1 \text{ cm}^2$  and a height equal to the height of the coal bed.

Assume also that the float is immersed in the liquid whose density varies in height in the same relationship as the changing of density of the solids coal bed. This task may be, for example, been solved by means of a magnetic fluid in a magnetic field. The magnetic field strength along the height of the vessel with a magnetic fluid is formed accordingly to achieve the desired distribution of the viscosity magnetic fluid along of the height (development of Chemical Technology University named after DI Mendeleev) [14, 16, 20, 21].

Different viscosity of the magnetic fluid in the different layers of the vessel leads to surface of solid non-magnetic inclusions. And each of those particles occupies a position corresponding to the density of the layer of magnetic fluid.

In this hypothetical experiment on a float with prismatic cross-sectional area  $S_n$ , submersed in a vessel filled with a fluid of variable density height *h*, will act the buoyancy force *F*, equal to the value:

$$F = S_i \int_0^h \rho_h \, dh. \tag{3}$$

Replacing the integral by sum with limits similar to the real fractional composition of

washed coal and assuming  $S_n = 1cm^2$ , we obtain:

$$F = \sum_{i=1}^{n} \rho_i \, dh. \tag{4}$$

To perform this virtual experiment fractional composition of initial coal was adopted from the source given in [5, 25, 27, 28]. Numerical data and graphic display of this fraction composition is shown in Table 1 and Fig. 2.

A graph given on Figure 2 shows the relationship between total yield fractions having a density greater than the density  $\rho_i$  and density  $\rho_i$ , constructed from the data in Table 1. A graph in Figure 3 shows the relationship between outputs of narrow fractions of initial coal from the density  $\rho_i$  constructed from the data same of Table 1.

Table 1. The relationship between the coal yield of fractions and their density

Fraction number i	Fraction density (g/cm <sup>3</sup> ) ρ <sub>i</sub>	Reference fractional composition F=171,75	
		Yield of narrow fraction (%) $\gamma_i$	Yield of fractions (%) density of which is greater then the density $\rho_i$
1	1,15	0,6	99,4
2	1,25	11,9	87,5
3	1,35	35,5	52,0
4	1,45	9,5	42,5
5	1,55	4,5	38,0
6	1,65	2,0	36,0
7	1,75	3,0	33,0
8	1,85	1,5	31,5
9	1,95	3,5	28,0
10	2,05	3,0	25,0
11	2,15	1,0	24,0
12	2,25	5,0	19,0
13	2,35	3,0	16,0
14	2,45	3,0	13,0
15	2,55	1,0	12,0
16	2,65	4,0	8,0
17	2,75	5,4	2,6
18	2.85	2.6	0



Fig. 2. Graph of the relationship between density  $\rho_i$  and total yield fractions having a density greater than the density  $\rho_i$ 



Fig. 3. Graph of the output of narrow fractions of initial coal

The graph in Figure 3 gives a visual representation of the contribution of each of the narrow coal fractions in the value of the elevating force of the float, calculated by formula (4).

According to Table 1, using the formula (4) let's calculate the elevating force of the float with  $S_n = 1cm^2$  which located at an altitude of all coal fractions each of them numerically equal to their output. In this case, the elevating force F is equal to:

$$F = \sum_{i=1}^{18} \rho_i dh = 171,75 \text{ g}/\text{cm}^2.$$

When the actual size of float sensor has the value  $Sn=300cm^2$  and more, elevating force exceeds 50 kg. Such elevating force ensures a stable position of the float in pulsating mixture of coal and water.

Jigger operator executes separation of coal concentrate from middlings and rock at the height of the coal bed in which fractions density are equal 1.5-1.8  $g/cm^3$ . Representativeness of the coal bed height measurement by given float sensor is defined follows. We assume measuring as is meaningful if the value of the buoyancy force acting on the float sensor placed in the coal bed may not be the same for different fractional compositions. Otherwise, such a measuring can not be considered to be meaningful, since for different heights of middle fractions sensor generates the same output signal.

Representativeness measure by float sensor of the height separating coal concentrate from the heavier fractions can be checked follows. An elevating force acts on a float which immersed in the coal bed.

To check the representativity the measured data of the height of the coal fractions, we must check whether exist another fractional composition of initial coal which provide the same elevating force for the float. To this end, a program was developed, generating Monte Carlo outputs of individual fractions according to equation of material balance and taking into account the patterns of distribution of output values. In these calculations the average values of output fractions remained unchanged. Block diagram of the program is shown in Fig. 4.

Studies have shown that equal elevating force (with honors to any small value, for example, such as 0.1%) can provide a variety of different combination of initial coal. Table 2 shows the two factional combinations obtained by calculation. For these combinations the value of elevating force F is the same (up to 0.1%) with a lifting force generated by the given fractional combination given in Table 1.

Let's note that despite the fact that two fractional cobinations of coal creates the same elevating force in the float sensor, the middle fractions are located at different heights of the coal layers in these two cases. For coal  $F = 171,65 \text{ g/cm}^2$  middle fractions located at a height of 10% higher (as judged by density) than those in the coal layers with a standard fractional composition. And for coal F=171,96 g/cm<sup>2</sup> middle fractions located at a height 5% lower than similar layers in the reference fractional composition.

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Fig. 4. Block diagram of calculating the density of the layer of coal bed measured by float sensor

<b>Table 2.</b> The relationship between density	$\rho i$ and total yield of fractions which density is greater than the density $\rho_i$
(for coals that create equal elevating force)	

		1-st fractional co	mposition of coal	2-nd fractional composition of coal			
		$\rho = 2.85$		$\rho = 2.85$			
Fraction density	$\sum \rho_i * \gamma_i$	=171.65	$\sum \rho_i * \gamma_i = 171.96$				
	<i>ρ</i> =1.15		$\rho = 1.15$				
numberi	(g/cm)		Yield of fraction		Yield of fraction		
	Pi	Yield of narrow	(%) density of	Yield of narrow	(%) density of		
	fraction (%)	which is greater	fraction (%)	which is greater			
			then the density $\rho_i$		then the density $\rho_i$		
1	2	3	4	5	6		
1	2	3	4	5	6		
1	1,15	0,6	99,4	3,6	96,4		
2	1,25	6,9	92,5	25,2	71,2		
3	1,35	40,5	52,0	11,9	59,3		
4	1,45	14,5	37,5	8,3	51,0		
5	1,55	4,5	33,0	4,5	46,5		
6	1,65	2,0	31,0	2,0	44,5		
7	1,75	3,0	28,0	3,0	41,5		
8	1,85	2,0	26,0	6,5	35,0		
9	1,95	1,0	25,0	5,7	29,3		
10	2,05	1,5	23,5	4,4	24,9		
11	2,15	1,0	22,5	4,0	20,9		
12	2.25	1.0	21.5	6.0	14.9		

1	2	3	4	5	6
13	2,35	1,5	20,0	2,2	12,7
14	2,45	2,0	18,0	3,0	9,7
15	2,55	1,0	17,0	2,0	7,7
16	2,65	4,0	13,0	4,0	3,7
17	2,75	6,4	6,6	3,1	0,6
18	2,85	6,6	0	0,6	0



**Fig. 5.** Relationship between density  $\rho_i$  and total yield fractions that having density greater than the density  $\rho_i$ . For the first graph, the force:

 $F = 171,65 \text{ g/cm}^2$ , for the second  $F = 171,96 \text{ g/cm}^2$ 

Figure 4 shows the relationship between the yield of fractions and their density for computed combinations of initial coal.

Taking into account the average bulk density of fine coal fractions (0.5-13mm) we can be roughly assumed that the distance between identical layers of middle fractions obtained by calculation of fractional composition of coal is 10-12% of the total height of the coal bed, which in absolute terms is approximately 5-6 cm.

Graphs of the three fractional compositions are shown in Fig. 6. The graphs depict the dependence total output of enriched coal from the density of these fractions.

Let's look at the vertical line intersecting all three graphs. We can see that positions of middle fractions separating coal concentrate and heavy products enrichment correspond to different outputs.

In particular, the difference between the output of the reference fraction composition and outputs the calculated fraction compositions reaches 6.5%. This means that there may be a situation in which the float will not respond to changes in the height of the average coal fractions.

For further calculations to be on the safe side we'll take measurement error equal to 1%, that is more than 5 times smaller than the error from the graphs in Fig. 6.

Taking the average performance of jigger130 t / h and the duration of the jigger work 20 hours in a day, we can calculate the amount of process losses due to measurement error of height of the coal bed, due to changes in the fractional composition of initial coal.

Such losses in one working day (130 \* 20 \* 1 %) may be about 25 tons of fuel mass, sent to waste, or about the same amount of high- fractions that had to send to waste, but due to a sensor error were sent to the second compartment of jigger.

The presented method of research of presentability of the float sensor does not claim to high accuracy of the results. But the evidence and clarity of the results indicates that the qualities of coal beneficiation of processes ACS in jiggers are strongly influenced from the degree of reliability of the information coming from the float sensor of height bed.



Fig. 6. Comparison disposition of the height of the various factions of the coals, which create equal lift when float switch is immersed in the coal bed

Indeed, if we assume that the output of float sensor signal is not showing the actual location of the narrow coal fractions in bed, then any regulator with any algorithms or corrective elements are not able to develop an effective control signal output value for successful control of jigger systems. At the same time, the graph in Figure 6, show that the effective use of coal bed height fractions sensor could successfully solve the problem of control of the parameters of jigger.

For the purpose of tracking the position of the certain layer can be applied float sensor, which checks only a certain fractions but not

checks coal bed as a whole. Whether can such a hypothetical sensor provide effective tracking of position of coal bed fractions height which changes due to fluctuations of the coal characteristics? For this purpose we represent as coal bed height sensor prismatic float with Sn=1cm<sup>2</sup> and height about the height of the coal fractions with a density of  $1.55-185 \text{ g/cm}^3$ . With the help of data available in Tables 1 and 2, we construct dependence of elevating force of this float sensor from the density of bed layers in which sensor was sinking. Obtained the dependencies of the elevating force for two calculated fractional compositions are shown in Table 3.

The data shown the third and sixth columns of Table expressed the specific value of lifting force of the float (in  $g/cm^2$ ) with a density of 1.65  $g/cm^3$  transported into layers of the coal bed of different density.

You may notice that the sign of the specific lifting force (i.e. the force action direction) is changing in the area of the average values of the height of the fractions of the coal bed. In this case information coming from such a sensor will allow to regulate the parameters of technological process of coal washing in jigs without disrupting process results.

### CONCLUSIONS

1. Studies suggest that the automatic control of two major subsystems of coal washing in jigs: oscillatory process control system for delamination of coal bed by density and discharge control system of heavy fractions used as input information the signal for measuring from float sensor. Was shown that in some cases output of the float sensor do not reflect the actual state of monitored coal fractions. The cause of such errors is to change the fractional composition of initial coal. This can cause significant deviations of output process parameters from the specified values.

2. The occurrence of significant measurement errors of height bed layers can be due to an excessive big zone of control coal fractions. Proved that to improve the accuracy of jigs ACS the height of float sensor must be close to the average value of the height of the middle fractions of coal bed.

Fractior	nal composition of F=171.75 g/cm	of given coal $n^3$	Fractional composition with altered location middle layer $F=171.65 \text{ g/cm}^3$			
Number of the layer of the narrow fraction (from sieve),%	The average density of the bed layer, $g/cm^3$ , $\gamma_i$	The difference between the calculated density and density of medium fraction	Number of the layer of the narrow fraction (from sieve),%	The average density of the bed layer, g/cm <sup>3</sup> , γ <sub>i</sub>	The difference between the calculated density and density of medium fraction	
10	2,68	1,03	10	2,72	1,07	
20	2,35	0,70	20	2,56	0,91	
30	2,03	0,38	30	1,91	0,26	
40	1,60	-0,05	40	1,47	-0,18	
50	1,38	-0,27	50	1,35	-0,30	
60	1,29	-0,36	60	1,28	-0,37	
70	1,25	-0,40	70	1,25	-0,40	
80	1,25	-0,40	80	1,25	-0,40	
90	1,20	-0,45	90	1,25	-0,40	
100	1,15	-0,50	100	1,18	-0,47	

Table 3. The elevating force of float sensor that is configured to measure the average fractions of initial coal

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#### ПОВЫШЕНИЕ ТОЧНОСТИ РАБОТЫ СИСТЕМЫ РАЗГРУЗКИ ПОРОДЫ И ПРОМПРОДУКТА В ОТСАДОЧНОЙ МАШИНЕ

#### Олег Лехциер

Аннотация. В статье представлены исследования по вопросу повышения точности работы измерения и регулировки высоты угольной постели - одного из самых важных параметров процесса обогащения угля в отсадочной машине. В статье выявлены недостатки существующих датчиков. Предложен путь совершенствования этих измерительных устройств. В статье предложен метод выполнения качественной оценки точности работы системы регулирования разгрузки породы и промпродукта в отсадочной машине.

Ключевые слова: отсадка, угольная постель, выход фракций, плотность, подъемная сила.

# Heat abstraction from contact zone of working elements of disc brake

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S u m m a r y. The work presents the results of theoretical and experimental research of influence of abstraction of part of heat power which is generated in friction contact zone on the process of mechanical braking due to the use of the system of forced cooling which is built on the base of recuperative oleopneumatic heat exchange apparatus. The mathematical description of the system of cooling of disk brake is given, checking of its adequacy is performed as well as the efficiency of the use of this cooling system on the basis of bench experimental testing. Recommendations concerning constructive parameters of cooling system necessary for its use at the rolling stock of railways are presented.

K e y w o r d s : disk brake, friction coefficient, braking effectiveness, cooling of friction contact zone.

#### **INTRODUCTION**

Braking tools of modern high speed trains reach the specific power consuming up to 40 MJ [2, 18, 19]. While absorbing such amount of energy during the braking the heating of friction elements is 800-900°C that causes instability of parameters of disk brake and as a result decreases the operating parameters of rolling stock which are connected with the necessity of compliance of prescribed braking distance and train schedules [11, 14, 16, 20].

Natural factor of the impact on the friction coefficient is cooling of operating friction elements of disc brake [1, 12, 15].

Existing constructions implement the principle of cooling of working elements due to the directing air flows to more thermally strained surfaces during the rotation of disk brakes but the effectiveness of such measures is not satisfactory because using them it is possible to outlet a small proportion of heat from the friction zone [9, 10, 17].

More effective is forced cooling of operating elements of friction brake due to the liquid which is a heat carrier and it is able to outlet enough amount of heat (up to 50%) [3] from the friction zone to the environment. This significantly stabilizes the friction coefficient.

# DESCRIPTION AND JUSTIFICATION OF USING THE PROPOSED COOLING SYSTEM

The basic scheme [4] of such system is presented at the Fig. 1. Heat that is generated in the contact of brake disk 1 with linings 2 is taken away from the outward surface of brake disk due to the elements for heat removal 3 which have the system of inner canals, the cooling liquid circulates through them. Their contact with the surface of brake disk is provided (and regulated) by the elastic elements 4. The transportation and cooling of liquid is carried out due to heat exchange apparatus 7.



Fig. 1. The scheme of the system of cooling of locomotive disc brake

The mathematical modeling of considered above cooling system is based on the joint mathematical description of following its elements and processes [5, 6]: contact of brace disk with linings (determination of the size of air flow which is generated during the braking); heating and cooling of brake disk material due to the heat conduction as well as convective and radiant heat exchange with the environment; contact heat exchange between brake disk and elements; functioning of heat exchange apparatus which cools the liquid that circulates through the elements for heat removal. The mentioned mathematical models are considered below.

The basis of the model is the equation of Fourier-Kirchhoff (1) in three-dimensional orthogonal coordinate system without internal heat sources considering convectional temperature change (Fig. 2).



Fig. 2. The estimated scheme of locomotive disc brake with elements of cooling system:

- 1, 4 outward surfaces of brake linings,
- 2, 3 outward surfaces of brake disk,
- 6, 7 outward surfaces of element for heat removal,

5, 8 - surfaces of contact of brake disk with linings and elements for heat removal severally

The model allows determining the temperatures of the considered surfaces of friction brake (both average integral and local) and also heat flows that come through the mentioned surfaces during the braking process:

$$\frac{\partial T}{\partial t} = \frac{1}{\rho \cdot c_{pm}} \cdot \left[ \frac{\partial}{\partial x} \left( \lambda \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( \lambda \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( \lambda \frac{\partial T}{\partial z} \right) \right] - (1) \\ - \left( v_x \frac{\partial T}{\partial x} + v_y \frac{\partial T}{\partial y} + v_z \frac{\partial T}{\partial z} \right),$$

where:  $\rho_m$  – specific mass,

t – current value of time during braking process,

c<sub>pm</sub> – specific isobar heat capacity,

 $\lambda_m$  – coefficient of thermal conductivity,

T - absolute temperature (T = f(x, y, z, t),

x, y, z – orthogonal coordinates),

 $v_x, v_y, v_z$  – projections of vector v of the linear speed of movement to the point of the outer surface with the coordinates x, y, z on the relevant coordinate axes.

There are following notations on the scheme:

R,  $R_{\kappa}$  – radius of brake disc and of locomotive wheel correspondingly,

 $r_0$ ,  $r_t$  – average radius of friction of lining and of element for heat removal correspondingly,

 $V_0$  – speed of oncoming air,

 $T_a$  – average air temperature far from the brake disc,

V<sub>d</sub> – current locomotive speed,

 $\overline{\varpi}$  – angular speed of rotation of brake disc,

 $\overline{a}^*$  – deceleration during braking,

 $\overline{\epsilon}$  – angular acceleration of the disc brake during braking.

Physical and thermophysical characteristics included in the equation (1) belong to the materials of brake disc, linings and elements for heat removal. For surfaces 1 -4, 6, 7 (Fig. 2) boundary conditions of the 3<sup>rd</sup> kind (combination of convective and radiant heat exchange without internal heat sources) are used:

$$\lambda_{m} \left( \frac{\partial T}{\partial n} \right)_{s} = \alpha \cdot (T_{s} - T_{a}) + \varepsilon \cdot \sigma \cdot (T_{s}^{4} - T_{a}^{4}), \quad (2)$$

where:  $\lambda_m$  – coefficient of heat conductivity,

 $\alpha$  – heat transfer coefficient between the corresponding surface and air,

 $\epsilon$  – degree of surface blackness (coefficient of emission),

 $\sigma$  – Stefan-Boltzmann constant,

n – unit vector (normal to the boundary of the study area).

Index «s» indicates that this value is assigned to the outer surface. For the surfaces 5 and 8 (sliding contact zone of brake disc with lining and element for heat removal correspondingly) boundary conditions of the  $4^{\text{th}}$  kind with surface heat source are used:

$$\lambda_{ml} \left( \frac{\partial T_1}{\partial n} \right)_s \pm q = \lambda_{m2} \left( \frac{\partial T_2}{\partial n} \right)_s$$

where: q – specific heat flow which is generated at sliding contact of brake disc with lining (sign "+") or which is removed by the element for heat removal (sign "-"). Here and further index "1" belongs to brake disc, index "2" – to lining or element for heat removal.

$$q(\mathbf{r},t) = \frac{1}{\iint r dS} \cdot \frac{\mathbf{m} \cdot \mathbf{R}_{\hat{e}}^2 \cdot \varepsilon}{n_n} \cdot \mathbf{r}(\mathbf{x},\mathbf{y}) \cdot (\omega^* - \varepsilon \cdot t),$$

where: m – braking mass,

 $n_n$  – number of braking linings that are involved in braking,

r – radius vector, that describes the contact zone of disc with lining (element for heat removal),

where x, y - current coordinates of the point on the surface S,

 $\varpi^*$  – angular speed of disc rotation that precedes braking ( $\varepsilon > 0$ ),

 $t \in [0;t_{\kappa}], t_{\kappa} = (V^* - V_{\kappa})/a^*$  – time of braking (time interval from the moment of the beginning of braking until reaching the final speed of movement by locomotive).

Here  $V_{\kappa}$  – final speed of the locomotive (a\* > 0), V\* – the speed of the locomotive that precedes braking. Other surfaces (that do not

shown at the Fig. 2) are considered to be thermally insulated.

The most important parameter of convective heart exchange between outward surfaces of elements of friction brake with environment is the coefficient of heat emission that is included to the equation 2. The peculiarity of this case is that forced convection is caused not only by air flow that blows longitudinally at the disc but also by disc rotation [13]. Moreover as the analysis shows these factors make approximately the same impact on the process of forced convection. Therefore the usage of speed of airflow which incidents on brake disc (considering the speed of oncoming wind and the rotation of the disk) as the heat transfer characteristics during the braking process allows considering heat transfer as stages of convective heat exchange which consistently change each other: forced convection, joint action of natural and forced convection, natural convection [7].

In order to determine the coefficient of heat emission  $\alpha$ , depending on the speed of the locomotive, the following criteria equations are proposed:

$$V_{d} = 0 \dots 15 \text{ km/hour :}$$

$$Nu = 0,4 \cdot (Re_{\omega}^{2} + Gr)^{0,25},$$

$$V_{d} = 10 \dots 35 \text{ km/hour :}$$

$$Nu = 0,18 \cdot [(0,5 \cdot Re_{\omega}^{2} + Gr) \cdot Pr]^{0,315},$$

$$V_{d} = 30 \dots 57 \text{ km/hour :}$$

$$Nu = 0,135 \cdot [(0,5 \cdot Re_{\omega}^{2} + Re_{a}^{2} + Gr) \cdot Pr]^{0,33},$$

$$V_{d} = 42 \dots 125 \text{ km/hour :}$$

$$Nu = 0,037 \cdot (Re_{a}^{0,8} + Re_{\omega}^{0,4}) \cdot Pr^{0,33}.$$
(3)

Reynolds number which are caused by the rotation of the brake disc  $(Re_{\omega})$  and by its blowing of oncoming air flow  $(Re_a)$ :

$$Re_{\omega} = \frac{4 \cdot \omega \cdot R^{2}}{v} = 4 \cdot \left(\frac{V_{d}}{R_{\kappa}}\right) \cdot \frac{R^{2}}{v},$$

$$Re_{a} = \frac{2 \cdot V \cdot R}{v},$$
(4)

where: v - kinematic viscosity of air,

 $V = V_d + V_0 = (V^* - a^* \cdot t) + V_0$  – current speed of the air flow which incidents on the brake disc, Grashof, Prandtl and Nuselta numbers for air:

$$Gr = 8 \cdot \beta \cdot g \cdot R^{3} \cdot (T_{s} - T_{a}) / \nu^{2}; Pr = c_{p} \cdot \mu / \lambda,$$

$$Nu = 2 \cdot \alpha \cdot R / \lambda,$$
(5)

where:  $\beta$  – coefficient of volumetric expansion of air,

 $\lambda$  – coefficient of thermal conductivity of air,

 $c_p$  – specific isobar heat capacity of air,

 $\mu$  – dynamic viscosity of air,

 $\alpha$  – surface heat transfer coefficient of brake disk.

For the first equation of the system 3 numbers of similarity  $Re_{\omega}$  and Gr are calculated in the following way:

$$\operatorname{Re}_{\omega} = \frac{\operatorname{V}_{d} \cdot \operatorname{R}^{2}}{\operatorname{R}_{\kappa} \cdot \operatorname{v}_{a}}; \quad \operatorname{Gr} = 8 \cdot \beta \cdot g \cdot \operatorname{R}^{3} \cdot \pi^{1,5} \cdot (\operatorname{T}_{s} - \operatorname{T}_{a}) / \operatorname{v}^{2}.$$

For the other equations of the system 3 specified numbers of similarity are defined by the expressions 4-5.

For modelling the work of recuperative heat exchanger apparatus in the system of active cooling of locomotive disc brake there was used a mathematical model based on the heat balance equation [8]:

$$Q = \int_{0}^{F} k_{i} \cdot \Delta t_{i} \cdot dF_{i} = k \cdot \Delta t \cdot F,$$

$$Q = Q_{1} = Q_{2} + \Delta Q,$$

$$Q_{1} = W_{1} \cdot (t_{1}^{'} - t_{1}^{"}); Q_{2} = W_{2} \cdot (t_{2}^{"} - t_{2}^{'}),$$

$$\Delta t = \frac{(t_{1}^{'} - t_{2}^{''}) - (t_{1}^{''} - t_{2}^{''})}{\ln \frac{t_{1}^{'} - t_{2}^{''}}{t_{1}^{''} - t_{2}^{''}}},$$

$$\delta t_{1} = t_{1}^{'} - t_{1}^{"} = (t_{1}^{'} - t_{2}^{'}) \cdot Z,$$

$$\delta t_{2} = t_{2}^{"} - t_{2}^{'} = (t_{1}^{'} - t_{2}^{'}) \cdot \frac{W_{1}}{W_{2}} \cdot Z,$$

$$Z = \frac{1 - e^{-(1 - W_{1} / W_{2}) \cdot (k \cdot F / W_{1})}}{1 - (w_{1} / W_{2}) \cdot e^{-(1 - W_{1} / W_{2}) \cdot (k \cdot F / W_{1})}},$$
(6)

where:  $Q_{1,2}$  – amount of heat given by hot (cooling liquid) and received by cold heat carrier (ambient air) correspondingly,

 $\Delta Q$  – heat loss to the environment,

 $\Delta t$  – medium integral temperature difference of heat carriers along the length of the heat exchanger,

 $t_1', t_1''$  – temperatures of hot heat carrier at the inlet and the outlet of the heat exchanger correspondingly,

 $t_2', t_2''$  – temperatures of cold heat carrier at the inlet and the outlet of the heat exchanger correspondingly,

k – total (complete) heat transfer coefficient of the heat exchanger,

 ${\rm F}$  – effective area of heat exchange surface,

 $W_{1,2}$  – water equivalent for hot and cold heat carriers correspondingly.

The system of equations 6 is constructed for the case of cross-scheme of heat carriers movement.

Effect of cooling on braking efficiency was evaluated by experimental determination of friction coefficient and temperature in the friction interaction zone under different operating conditions of the last one.

# EXPERIMENTAL RESEARCH AND VERIFICATION OF MATHEMATICAL MODEL ADEQUACY

Experimental research of braking process was performed using a laboratory full-scale brake bench. The bench allows to accumulate kinetic energy, to record the frequency of rotation and the duration of the drive work and to register the following input parameters of brake and drive as: braking moment, efforts of braking traction, braking time, temperature of friction surfaces.

The design of the bench provided the item purpose of which is to remove heat from the contact zone of disc and pad. It is a container dimensions of which are caused by the estimated amount of heat that is required to take out from the work area. The container is connected with the heat exchanger. The cooling section of the locomotive 2TE116 (the effective area of heat exchange  $\approx 52 \text{ m}^2$ ) was used as the heat exchanger. It was cooled by means of an axial fan BOK-4,0 (with a maximum productivity of 4500 m<sup>3</sup>/hour). The maximum discharge of heat carrier (water) was 0.9 m<sup>3</sup>/hour. The effort of pressing of element for heat removal to friction disc (in this case to the brake pulley with diameter of 200 mm) was controlled with model dynamometer and was in the range 0.05...0.1 kN.

The results of this series of experiments are presented at Fig. 3. Thus Figure 3 (a) shows the nature of the change of the frictionslip coefficient during the braking (t – time during braking), and Fig. 3 (b) shows the average temperatures of contacting friction surfaces.



 $<sup>\</sup>circ$  – removal of ~50% of generated heat energy;

– theory

Fig. 3. Friction coefficient (a) and average temperature (b) of frictional interacting surfaces during braking

 $<sup>\</sup>Delta$  – removal of ~25% of generated heat energy;

 $<sup>\</sup>Box$  – cooling system does not function;

The initial rotational speed of the brake pulley was equivalent of the linear speed of movement of 60 km/hour. The value of the linear deceleration during braking was  $1 \text{ m/s}^2$ . The experimental values shown on the graph were obtained by averaging a series of parallel measurements. The boundaries of confidence intervals correspond to confidence probability of 0.95. On the graphs shown in Figure 3 (b) only halves of the symmetric confidence intervals are built in order to improve the perception of information. The values of heat energy which is given out by the cooling system (shown on the graphs) were evaluated theoretically using mathematical models considered above. Finite element method using the software package Comsol Multiphysics® was used for solving the differential equations in partial derivatives of the form 1-2. The estimated three-dimensional grid consists of 583247 tetrahedral. The outward surfaces 3 (Fig. 2) contains 48424 triangles, surfaces of contact 5 and 6 contain 2924 and 2108 triangles correspondingly (the maximum size of the element for surfaces 3, 4 and 6 does not exceed 0.005 m).

### CONCLUSIONS

1. There was proposed the system of forced liquid-air cooling of working elements of disc brake, the heat carrier is process water. There is the element for heat removal in the construction of the brake. It provides dose removal of heat that generates in the contact zone.

2. In the case of using as a heat carrier technical water or close to it on thermophysical properties liquid with a maximum operating temperature of 363 K which is cooled by the atmosphere air with its initial temperature of 298 K for abstraction of 100 kW of heat energy it is necessary the following surface area of heat exchange:

direct flow scheme of heat carriers movement: 190...960 m2,

cross scheme of heat carrier movement: 100...420 m2.

3. It is shown theoretically that the offset from 50 to 100 kW may be provided by liquid-air lamellar heat exchanger with dimensions: from  $340 \times 875 \times 925$  mm to  $950 \times 1325 \times 1145$  (effective surface area from 82 to 157 m2, the average coefficient of heat transfer is from 38 to 45 W/(m2·K),) when using a fan with productivity from 4750 to 14500 m3/hour and discharge of hot heat carrier (water) from 1.02 to 1.34 m3/hour.

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#### ОТВОД ТЕПЛОТЫ С ЗОНЫ КОНТАКТА РАБОЧИХ ЭЛЕМЕНТОВ ДИСКОВОГО ТОРМОЗА

#### Юрий Ю. Осенин, Игорь Соснов, Оксана Сергиенко, Ирина Белобородова

Аннотация. В работе представлены результаты теоретико-экспериментального исследования влияния на процесс механического торможения отвода части тепловой энергии, генерируемой в зоне фрикционного контакта, за счет использования системы принудительного охлаждения, построенной на базе рекуперативного жидкостно-воздушного теплообменного аппарата. Приведено математическое описание системы охлаждения выполнена проверка его дискового тормоза, также эффективности адекватности, а использования данной системы охлаждения на основе стендовых экспериментальных испытаний. Представлены рекомендации относительно конструктивных параметров системы охлаждения, необходимые для ее использования на подвижном составе железных дорог.

Ключевые слова. дисковый тормоз, коэффициент трения, эффективность торможения, охлаждение зоны фрикционного контакта.

# Synthesis of extreme control system of coal cleaning in jigs

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S u m m a r y: The research of the behavior of the extremum of the quality criterion. A method for finding the extremum of the criterion of efficiency for the example of jigging. Made extreme synthesis and simulation control system. The dynamics of extreme systems and identify indicators of quality.

K e y w o r d s : Jigging, coal cleaning, density, yield of fractions, performance criterion, extremal system

#### **INTRODUCTION**

The most important and complex processes concentrators are coal processing different engine classes in jigs and flotation machines, heavy media gravity separation and hydrocyclones.

In accordance with technological scheme of processing of coal are three levels of management [14, 15]: lower level provides management regime parameters most closely correlated with the quality of enrichment products (density separation bed height breed, specific consumption of reagents, etc.), medium – provides process control (separate concentrator machine or group of machines of the same type, for example, a few jigs), upper - provides management of the complex processes of coal preparation (all jigging, machine, separators flotation and hydrocyclones operating on a common product.)

As you know, each level of the hierarchy of control should be carried out by a given criterion when extremalization general criterion. This should be observed hierarchy of criteria: lower levels of management must obey superiors. As a criterion of control is advisable to choose a criterion that could be quickly calculated on the basis of information received from automatic devices have a physical meaning, uniquely determine the effectiveness of the factory and does not contradict the generally accepted criteria [26].

#### MATERIALS AND METHODS

Synthesis of extremum search criterion of efficiency is made by the method of measuring the sign of the derivative [16, 24, 32].

#### **RESULTS, DISCUSSION**

In general, coal beneficiation process can be represented as the transformation of raw coal input stream to the output stream of commodity products and wastes:

$$Y = L\{X, V, Z\},\$$
$$A_{k\min}^{d^*} \le A_k^d(t) \le A_{k\max}^{d^*}, \ A_0^d(t) \ge A_0^{d^*}(t), \quad (1)$$

where: X – vector input characteristics of raw coal, V – vector control actions, Z – vector of disturbances, Y – vector output characteristics of products,  $A_k^d(t)$ , – ash content,  $A_k^d(t)$ ,  $A_{k\min}^{d*}$ ,  $A_{k\max}^{d*}$  – specified minimum and maximum ash content,  $A_0^d(t)$ , – current ash waste,  $A_0^{d*}(t)$  – given ash waste, L– оператор преобразования.

For practical application given criterion can be simplified by considering the amount of output per unit of time. Then, given the constancy of the list price and coal washability curve approximation of second-order polynomial [8, 25], we obtain a mathematical expression control objectives as follows:

$$I(A_{k\Sigma}^{d}) = \sup M \left\{ \sum_{i=1}^{n} G_{i} \left[ a_{0i} + a_{1i} A_{k}^{d} + a_{2i} \left( A_{k}^{d} \right)^{2} \right] \times \right\}$$
  
 
$$\times \left[ 1 - \lambda \left( A_{ki}^{d} - A_{ki}^{d*} \right) \right], \qquad (2)$$

where:  $G_i$  – initial performance of i-th class machine,  $a_{0i}, a_{1i}, a_{2i}$  – approximating polynomial coefficients of i-th class machines,  $A_{ki}^d, A_{ki}^{d*}$  – given the current (list price) ash concentrate for the enrichment i-th engine class,  $A_{k\Sigma}^d$  – total ash content of coal concentrate,  $\lambda$  – rate discounts or surcharges on the price of coal concentrate at a deviation of ash coal concentrate from the list price.

This should be the following restrictions on ash content and losses:

$$A_{k\Sigma\min}^{d^*} \le M\left\{A_{k\Sigma}^d(t)\right\} \le A_{k\Sigma\max}^{d^*},\tag{3}$$

$$M\left\{A_{0}^{d}(t)\right\} \geq A_{0}^{d^{*}}, \ \nu_{n}(t) \leq \nu_{n}^{*},$$
(4)

where:  $A_{k\Sigma\min}^{d^*}$ ,  $A_{k\Sigma\max}^{d^*}$  – allowable minimum and maximum total ash content of the concentrate,  $v_n(t)$ ,  $v_n^*$  – current and allowable losses concentrate tailings

$$A_{k\Sigma}^{d} = \frac{M\left\{\sum_{i=1}^{n} \gamma_{ki} A_{ki}^{d}\right\}}{M\left\{\sum_{i=1}^{n} \gamma_{ki}\right\}},$$
(5)

where:  $\gamma_{ki}$  – concentrate output of i-th class machine.

Not hard to see that (2) for each class has an extreme high-drifting in the vertical and horizontal directions with changes in productivity and coal washability. In the absence of constraints (3), (4) the maximum of (2) takes place at the maxima for each machine class, ie particular criteria are additive to the total.

In the case of restrictions on the ash content, which usually has a more stringent requirement of the form  $A_{k\Sigma}^d \leq A_{k\Sigma}^{d*}$  ( $A_{k\Sigma}^{d*}$  – given the total ash content of the concentrate), the maximum of (2) takes place at the optimum values ash content of each class of machine, different from their extreme values [27]. In this case, the problem of determining the optimal values of ash content of each class of machine can be reduced to a linear programming problem.

Depending on the location of the extremum of target function along the axis of ash content of the concentrate can be used and the appropriate management strategy separation process.

Consider the criterion (2) for the plant as a whole. For this we represent (2) as a function of ash content mixture of concentrates:

$$I(A_{k\Sigma}^{d}) = \sup M\left\{\sum_{i=1}^{n} G_{\Sigma}\left[a_{0\Sigma} + a_{1\Sigma}A_{k\Sigma}^{d} + a_{2\Sigma}\left(A_{k\Sigma}^{d}\right)^{2}\right] \times \left[1 - \lambda\left(A_{k\Sigma}^{d} - A_{k\Sigma}^{d^{*}}\right)\right]\right\}$$

$$(6)$$

where:  $G_{\Sigma}$  – total load on the section of the factory,  $a_{0\Sigma}, a_{1\Sigma}, a_{2\Sigma}$  – approximating polynomial coefficients of total  $\beta$ -curve of mix all engine classes.

Extremum-maximum criterion (6) drifts in the horizontal direction, as when changing raw coal washability and also change the coefficients of the polynomial approximating  $\beta$ -curve [7, 20]. And an upgrade washability extremum shifted to higher ash content as  $\beta$ curve is approximated by a convex function. The maximum of criterion (6) also drifts in the vertical direction when changing coal washability and load the initial product.

For example, for coking coal of the Donets Basin (factory "Sukhodilska") plot of the optimality criterion on the ash content of the concentrate mixture has an extrememaximum in the  $A_{k\Sigma}^d = 14\%$ . The norm of ash concentrate for this plant is 8.5%, so the work in this mode is not acceptable. This is due to the low value of the coefficient  $\lambda$ . In the case of its increase extremum of the criterion is shifted to lower ash content.

This indicates that the management of the complex at the existing price system should be implemented at the boundary permissible region. Must take into account constraints (3) due to the inability in many cases provide an extremum of the objective function at the average, difficult and very difficult categories of coal washability.

If concentrates different engine classes do not mix (for example, anthracite coal concentration), the ash content of each class is limited to a range of  $A_{k\min}^d \div A_{k\max}^d$ . Extremum efficiency criterion (2) takes place at extremes of this criterion for each of the classes. Since the implementation is carried out by grades of anthracite, if restrictions on its ashes must consider this limitation in concentration of each class.

For practical applications, it is advisable to the objective function of complex control processes of coal preparation expressed through the performance of each department to concentrate:

$$I(A_{k}^{d}, G_{k}) = \sup M\left\{\sum_{i=1}^{n} G_{ki} \cdot \left[1 - \lambda \left(A_{ki}^{d} - A_{ki}^{d^{*}}\right)\right]\right\}, (7)$$

with constraints (3) and (4).

In view of the above criteria's property management factory unprofitable to work with  $M\left\{A_{k\Sigma}^{d}(t)\right\} < A_{k\Sigma}^{d*}$ , so it is advisable to use the above limitation of the equal sign. This means that the restrictions on the ash content is almost always forced to work in the ash stabilization modes. Then the maximum value of sales equivalent to the maximum specified output concentrate ash content, ie criterion "concentrate output" is a special case of performance criteria.

Thus, the automatic control system to individual coal preparation process, in most ash content should provide cases the stabilization of the concentrate and it sometimes optimization. Control system for preparation processes should coal also stabilize the ash mixture concentrates all engine classes or to provide optimization of the complex. At the heart of optimization systems can be used stabilizing system, which targets are set on the basis of objective function extremalization.

So ash content and performance at coal concentrate of local processes selected by minimizing the cost of enrichment:

$$I_{11} = \sum_{i=1}^{n_{\phi}} C_{\Pi i} G_i \left[ 0,01 \sum_{p=0}^{k_{\phi}} a_{pi} \left( A_{\kappa i}^{d^*} \right)^p \right] \times \\ \times \left[ 1 + \sum_{\nu=1}^{m_{\phi}} \lambda_{\nu i} \left( W_{\nu i} - W_{\nu i}^* \right) \right] \rightarrow \min,$$
(8)

where:  $I_{11} \in \mathbb{R}$  – total cost of coal preparation UAH/h.,  $C_{\pi i} \in \mathbb{R}$  – cost of coal preparation class i, UAH/t (in general depends on the output of concentrate),  $n_{\phi} \in \mathbb{Z}$  – the number of machine classes,  $m_{\phi} \in \mathbb{Z}$  – the number of corrective parameters rates (ash content, moisture, sulfur, etc.),  $k_{\phi} \in \mathbb{Z}$  – order approximating polynomial [20], p,v,i  $\in \mathbb{Z}$  – auxiliary parameters,  $p=1,...,k_{\varphi}$ ,  $v=1,...,m_{\varphi}$ , i=1,...,n<sub> $\phi$ </sub>, G<sub>i</sub> $\in$ Z – load the i-th class machine, t/h,  $A^{d^*}{}_{\kappa i} \in \mathbb{R}$  – calculated ash content of i-th engine class, %,  $a_{pi} \in \mathbb{R}$  – coefficients of the polynomials,  $W_{vi}, W^*_{vi} \in \mathbb{R}$  -current and set values of the parameter v-th (ash, moisture, sulfur, etc.) of i-th engine class,  $\lambda_{vi} \in \mathbb{R}$  – weighting parameter deviation of i-th class machine (ash, moisture, sulfur, etc.) from setpoint.

Criteria for quality control of coal preparation for local processes must not contradict the global criterion controls the coal preparation plant (2.1) [14]. On the lower level criteria used stabilization regime parameters. Perform synthesis system of extreme control of the local coal jigging process. Jigging efficiency to the greatest extent determined by the height of bed H and its coefficient of looseness R. Dependence of the efficiency criterion I of the H and the R has an extreme character [17, 29, 30]. A significant portion of the useful components lost waste at low altitude bed. Weediness of the product of high-components increases at high altitude bed, which leads to an increase in the ash content of the concentrate.

Carried out in [31] analysis showed that the most effective control is to change the setpoint height of bed H:

$$G_n = 108 - 719H_n + 1192H_n^2, \tag{8}$$

$$\gamma_n = 30.7 - 182H_n + 276H_n^2, \tag{9}$$

$$G_{nn} = 7,25 - 31,1H_{nn} + 99,9H_{nn}^2, \tag{10}$$

$$A_k^d = -7.62 + 235H_{nn} - 885H_{nn}^2, \tag{11}$$

where:  $G_n, G_{nn}$  – respectively discharging device performance in the first and second branch of the jigger,  $H_n, H_{nn}$  – respectively bed height,  $\gamma_n$  – rock weediness.

Dependence of the efficiency criterion *I* of the height of the coal bed *H* was obtained after substituting (8) - (9) and (10) - (11) (for given values  $\gamma_{n_3} = 2,2\%$  and  $A_{k_3}^d = 6,3\%$ ), respectively, in the equation:

$$I_3 = 6,5 - 0,7G_{nn} - 2,5(\Delta A_{\kappa}^d)^2,$$

where:  $\Delta \gamma_{\bar{i}} = \gamma_{\bar{i}} - \gamma_{\bar{i}c}$ ,  $\Delta A_{\kappa}^d = A_{\kappa}^d - A_{\kappa_3}^d$ .

Performance criteria for the first and second branch of the jigger respectively have the form:

$$I_2 = 3,09 - 1,58 \cdot 10^4 H_n^2, \tag{12}$$

$$I_3 = 3,56 - 2,48 \cdot 10^3 H_{nn}^2.$$
(13)

As can be seen from the dependence of the efficiency criterion from control for both branches of the jigger is of an extreme nature and has a positive extremum-maximum.

Thus, changes in the fractional composition and ash content of raw coal has a significant impact on output variables jigging process that leads to the drift maximum efficiency criterion.

Perform synthesis system of extremum search for the example of jigging [4, 5, 9]. The transfer function of a control object (second division) for the channel performance unloader  $G_{mn}$  – height of the bed  $H_{mn}$  is [12,13]:

$$W(P) = \frac{K \exp(-p \tau)}{Tp+1},$$

where:  $K = 2,2 \cdot 10^{-4}$  – transfer coefficient m/kg, T = 75 – time constant, sec,  $\tau = 50$  – transport delay, sec.

Fig. 1 is a functional diagram of ACS jigging [33].

$$I_2 = 2,2 + 0,3G_i - \Delta \gamma_i^2,$$



Fig. 1. Functional diagram of a process control system

This schema contains two blocks of differentiation *BD*, division unit *DU*, that defines the derivative dI/dH, and relay element *RE*, which determines the sign of the derivative [10,11,18]. Depending on the sign of the derivative control device *CD* provides movement of control object in the direction of extreme. Derivative changes sign when passing through an extremum, relay element switches and a control device changes the sign of the output signal to the other  $\pm m$ , which ensures the system returns to the point of extreme. Value of the derivative dI/dH is determined from the expression:

$$\frac{dI}{dH} = \frac{dI}{dt} / \frac{dH}{dt}.$$
 (14)

Fig. 2 shows a timing diagram illustrating the operation of the extremal system [19, 23, 28]. Let the initial state of the system is determined by the point  $M_1$  located on the left of the extremum. In this case

dI/dH > 0 and the signal +m is input to the *CD*. *H*-value increases at a constant rate. Quality Score *I* will rise first, and then after the extremum point - decrease. Derivative dI/dH before an extremum positive, derivative is zero at the extremum point, and after the extremum point becomes negative. The derivative is negative to the point  $M_2$  because of the dead zone in the ER. When dI/dt = -kc, where 1/k = dI/dt, *RE* witches and changes sign at input *CD*. Thereafter *H* decrease at a constant rate and quality score *I* increase until it enters the extremum point, etc. The system established by oscillations with a period *T*.

Fig. 3 shows the implementation of control systems in Simulink application [6].

The control device is implemented as a function of Matlab (Fig. 4).

The simulation results of the extremal system shown in Fig. 5-10.



Fig. 2. System operation



Fig. 3. Simulation of the system in Simulink



Fig. 4. Calculation of control action



Fig. 5. Changing performance unloader  $G_{nn}$ 



Fig. 6. Search extremum of the functional quality



**Fig. 7.** Changing the value of the derivative dI/dt



**Fig. 8.** Changing the value of the derivative dH/dt



Fig. 9. Changing the value of the derivative dI/dH



Fig. 10. Signal at the output relay element

Dynamics of systems characterized by extreme parameters such as: search costs, hunting period, the search area at the input and output of the object, time to the point of extreme [1, 3]. We define these parameters for extreme system. Relay element is the perfect three-point relay with dead zone 2 sec.

We assume that the I = f(H) has the form of a parabola, then if origin of coordinates moved to the extremum point, the nonlinear part of the object is described by the equation:

$$I = -k_1 H^2 \,. \tag{15}$$

Assume that *H* varies linearly in the mode steady-state oscillation, i.e.:

$$H = \pm k_2 t, \tag{16}$$

where: the sign "+" corresponds to the time interval when dH/dt > 0, and the sign "-" – the time interval when dH/dt < 0. In this case:

$$I = -k_1 k_2^2 t^2 \,. \tag{17}$$

In the steady-state oscillation maximum deviation (amplitude yaw) of the quality of the extreme value is determined from the expression (14) for t = T/2:

$$\Delta I = -k_1 k_2^2 T^2 / 4 \,. \tag{18}$$

Define the derivative dI/dH, for this we write the derivative of the quality time:

$$dI/dt = -2k_1k_2^2t ,$$

and derivative dH/dt:

$$dH/dt = \pm k_2$$
.

Then:

$$dI/dH = \frac{dI/dt}{dH/dt} = \pm 2k_1k_2t.$$

Switching *RE* occurs when  $dI/dH = \pm c$ and t = T/2 if origin of coordinates moved to the extremum point:

$$2k_1k_2T/2 = c,$$

Which implies that:

$$T = c / k_1 k_2,$$

i.e. period depends on the hunting deadband relay element, and is determined by parameters of *CD* and extreme characteristics of the object.

The average deviation of the quality for the period is called loss on the hunting D. It is determined from the integral:

$$D = \frac{1}{T} \int_{0}^{T} I(t) dt = \frac{2}{T} \int_{0}^{T/2} -k_1 k_2^2 t^2 dt = \frac{-k_1 k_2^2 T^2}{12} .$$
(19)

#### CONCLUSIONS

1. Studies of coal preparation in heavy media gravity separation (class 13 mm) in jigs (class 1-13 mm) and flotation machines (class 0-1 mm) lead to the following conclusions [2,21,22]:

• dependence  $I(A_{k\Sigma}^d)$  has a maximum, which drifts in vertical and horizontal directions,

• to increase washability extremum shifted to the right in the area of high ash content,

• operation of the process at the extremum of the functional quality within the permissible ash is only possible for the light category coal washability.

2. Therefore, in most cases, the optimal mode of any coal beneficiation processes is the stabilization mode maximum ash content of the concentrate with constraints on the ash content.

3. The results of calculations of quality extremal system: amplitude of the hunting  $\Delta I = 0.025$ , search costs -D = 0,075. The average value of the ash content of the concentrate  $\overline{A}_k^d = 6,25\%$ , standard deviation  $-\sigma_A = 0,15\%$ .

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#### СИНТЕЗ ЭКСТРЕМАЛЬНОЙ СИСТЕМЫ УПРАВЛЕНИЯ ПРОЦЕССОМ ОБОГАЩЕНИЯ УГЛЯ В ОТСАДОЧНОЙ МАШИНЕ

#### Алексей Письменский, Виталий Ульшин

А н н о т а ц и я. Исследовано поведение экстремума критерия качества. Предложена методика поиска экстремума критерия эффективности на примере процесса отсадки. Выполнен синтез и моделирование экстремальной системы управления. Исследована динамика экстремальной системы и определены показатели качества.

К л ю ч е в ы е с л о в а: отсадка, угольная постель, выход фракций, критерий качества, экстремальная система

# Influence of construction parameters on traction qualities of conveyor on an air cushion with inclined round channels

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S u m m a r y. The mathematical model that determines influence of construction parameters on traction qualities of conveyor on an air cushion with inclined round channels is obtained and experimentally tested. Using the obtained mathematical model, influence of construction parameters on traction qualities of conveyor on an air cushion with inclined round channels is investigated.

Key words: conveyor, air cushion, lift force, traction force

#### INTRODUCTION

At the modern industrial enterprises the main volume of loads transportation is carried out by means of conveyor transport to which, in particular, conveyors on an air cushion with inclined round channels belong. Conveyors on an air cushion with inclined round channels represent one of perspective types of conveyor transport. These conveyors can be used for transportation of loads on separate technological operations in line production (Fig. 1, a), for transportation of loads in warehouses in the course of an order complete set (Fig. 1, b), for transportation of loads through hardening, heating, drying furnaces



Fig. 1. Characteristic examples of use of conveyors on an air cushion with inclined round channels: 1 - air receiver, 2 - nozzle, 3 - channel, 4 - container, 5 - guide

and cooling cameras (Fig. 1, c), and also for other transport and logistic operations which are connected to transportation of piece loads. Owing to absence of a traction organ, and also the drive, conveyors on an air cushion with inclined round channels in comparison with traditional types of conveyors have a row of somehow: simplicity advantages, of construction, the low level of noise, safety of maintenance in an explosive environment, possibility of combination of operations of transportation and heat treatment of loads. However, despite existence of these advantages, conveyors on an air cushion with inclined round channels have rather limited application. This circumstance is connected to small study of these conveyors, in particular, their traction qualities.

# MATERIALS AND METHODS

The simplest theory of the device, made in the form of conveyors on an air cushion, in which the bearing layer is formed by the system of discrete air jets, was proposed by Bobrov V. [1]. A contribution to the development of theory of vehicles on the air cushion was made by Bitukov V., Kolodezhnov V. [2, 3], Khanzhonkov V. [5, 6], Murzinov V. [9], Nechaev G. [10], Pang M. [11], Sarsenova G. [13], Song R. [14], Turushin V. [15-18] and other scientists. But the questions that relate to the study of influence of construction parameters on traction qualities of conveyors on an air cushion with inclined round channels were not studied in the works of these authors.

The research results of aircrafts and ships with support devices on an air cushion are presented in work of Lu J., Huang G., Li S. [7, 8], Yun L., Bliault A. [19], Zalewski W. [20], Zhou J., Guo J., Tang W., Zhang S. [21, 22]. In work of Dreszer K.A., Pawlowski T., Zagajski P. [4] the process of grain transportation by means of screw conveyors is studied. However, the results of this works may not be used in the study of traction qualities of conveyors on an air cushion.

The scientific work of Złoto T. and Nagorka A. [23] is devoted to research of the pressure distribution of oil film in the variable height gap between the valve plate and cylinder block in the axial piston pump. But, physical properties of air and oil are various different. Thus, transferring obtained in this work the results for the case of conveyors on an air cushion with inclined round channels is not possible.

#### AIM AND TASKS OF RESEARCH

The aim of our research is analysis of influence of construction parameters on traction qualities of conveyor on an air cushion with inclined round channels. To achieve this aim it is necessary to solve the following tasks:

- obtainment of mathematical model that determines influence of construction parameters on traction qualities of conveyor on an air cushion with inclined round channels,

- experimental test of the obtained mathematical model,

- study of the obtained mathematical model.

## **RESULTS OF RESEARCH**

For load that moves through the conveyor on an air cushion with inclined round channels (Fig. 2.), Newton's second law is:

$$m\vec{a} = \vec{F}_v + \vec{F}_x + \vec{G} + \vec{W},$$
 (1)

where: m – the load mass,  $\vec{a}$  – the load acceleration,  $\vec{F}_y$  – the lift force,  $\vec{F}_x$  – the traction force,  $\vec{G}$  – the load weight,  $\vec{W}$  – the motion resistance force.



Fig. 2. Calculation scheme of the conveyor on an air cushion with inclined round channels

$$ma = F_x - W$$

from which:

$$F_x = W + ma . \tag{2}$$

Due to the fact that the motion resistance force is determined by the relation:

$$W = wG$$
,

mass and weight are connected by the depend:

$$m = G/g$$
,

and also that:

$$G=F_y,$$

where: w – the motion resistance force coefficient, g – the free fall acceleration, Eq. 2 can be written in the form:

$$F_x = F_y \left( w + \frac{a}{g} \right). \tag{3}$$

Accepting that the movement of load is uniformly accelerated and that the initial velocity of the load is equal to zero, we obtain:

$$a = \frac{2L}{t^2},\tag{4}$$

where: L – the conveyor length, t – the time of load transportation.

The time of load transportation can be calculated by the formula:

$$t = \frac{L}{V_a},\tag{5}$$

where:  $V_a$  – the load average velocity. Substituting Eq. 5 to Eq. 4, we will have:

$$a = \frac{2V_a^2}{L}.$$
 (6)

It is known that:

$$V_a = \frac{Zs}{3600},$$

where: Z – the hour piece conveying capacity, s – the step between loads. In the case of transportation of loads with little intervals it is possible to consider that  $s \approx l$ . Taking this into account, we get:

$$V_a = \frac{Zl}{3600}.$$
 (7)

Substituting Eq. 7 to Eq. 6, finally we obtain:

$$a = \frac{Z^2 l^2}{6,48 \cdot 10^6 L} \,. \tag{8}$$

Because of the Eq.8, the Eq. 3 can be written as:

$$F_x = F_y \left( w + \frac{Z^2 l^2}{6,48 \cdot 10^6 Lg} \right)$$

or, having divided right and left parts of this equation for  $F_v$ :

$$\frac{F_x}{F_y} = w + \frac{Z^2 l^2}{6,48 \cdot 10^6 Lg}.$$
 (9)

The structure of expression, which is in the left part of the Eq. 9, similar to well-known expression of the dynamic factor of the car and, taking into account aerodynamic nature traction and lifting forces, may be called aerodynamic factor of conveyor on air cushion with inclined round channels:

$$A = \frac{F_x}{F_y}.$$
 (10)

Unlike traction force, aerodynamic factor, which represents the ratio traction force to lift force, allows not only to quantify, but also to compare traction qualities of conveyors on air cushion with inclined round channels.

In view of the above we will have:

$$A = w + \frac{Z^2 l^2}{6,48 \cdot 10^6 Lg}.$$
 (11)

The Eq. 11 is an equation of traction balance of conveyor on air cushion with inclined round channels.

The traction force and lift force are defined as follows:

$$F_x = c_x p_0 S \,, \tag{12}$$

$$F_y = c_y p_0 S, \qquad (13)$$

where:  $c_x$  – the traction force coefficient,  $c_x$  – the lift force coefficient,  $p_0$  – the air pressure in the receiver, S – the area of the load support surface. Substituting the Eq. 12 and the Eq. 13 in the Eq. 10,

$$A = \frac{c_x}{c_y}.$$
 (14)

Using the results of previously conducted research [12, 16], the Eq. 14 can be represented in the form:

$$A = \frac{64(H+h)^2}{d^2} \left[ 1 - \frac{H+h}{0.5d} \left( 1 - e^{-\frac{0.5d}{H+h}} \right) \right]^2 \times \frac{(b+l)^2 h^2 \sin \varphi}{\overline{S_1} b^2 l^2} : \left( 1 + \frac{64(H+h)^2}{d^2} \left[ 1 - \frac{H+h}{0.5d} \times \left( 1 - e^{-\frac{0.5d}{H+h}} \right) \right]^2 \frac{(b+l)^2 h^2 \cos \varphi}{\overline{S_1} b^2 l^2} + 2 \left\{ 1 - \frac{16}{d^2} \times \left( (H+h)^2 \left[ 1 - \frac{H+h}{0.5d} \left( 1 - e^{-\frac{0.5d}{H+h}} \right) \right]^2 \right\} \right\}$$

$$\times \frac{(b+l)^2}{\overline{S}_1 b^2 l^2} h^2 / \cos \varphi \bigg), \qquad (15)$$

where: H – the depth of the cavity on the side of the load support surface, h – the thickness of an air cushion, d – the diameter of channels,  $\overline{S}_1$  – the relative area of channels,  $\varphi$  – the incline angle of channels, b – the load width, l – the load length.

The Eq. 15 is the mathematical model that determines influence of construction parameters on traction qualities of conveyor on an air cushion with inclined round channels.

For validation of the obtained mathematical model an experiment was conducted on test stand (Fig. 3-5).



Fig. 3. Test stand for research of conveyors on an air cushion with inclined round channels



Fig. 4. Platform, which simulates the transported load



Fig. 5. General view of the strain gauge

In the result of conducted experiment the following empirical model was obtained:

$$\begin{split} A &= -2394, 7 \cdot 10^{-6} + 7893, 3 \cdot 10^{-6} h + \\ &+ 39, 6 \cdot 10^{-6} \varphi + 227, 0 \cdot 10^{-6} d + \\ &+ 1020, 0 \cdot 10^{-6} \overline{S}_1 + 655, 3 \cdot 10^{-6} H + \\ &+ 209, 3 \cdot 10^{-6} h \varphi - 1480, 0 \cdot 10^{-6} h d - \\ &- 6720, 0 \cdot 10^{-6} h \overline{S}_1 + 3533, 3 \cdot 10^{-6} h H - \\ &- 17, 5 \cdot 10^{-6} \varphi d - 58, 8 \cdot 10^{-6} \varphi \overline{S}_1 + \\ &+ 45, 4 \cdot 10^{-6} \varphi H + 716, 0 \cdot 10^{-6} d \overline{S}_1 - \\ &- 262, 0 \cdot 10^{-6} d H - 1656, 0 \cdot 10^{-6} \overline{S}_1 H \end{split}$$

where: h – the thickness of an air cushion in the range from 0.2 to 0.5 mm,  $\varphi$  – the incline angle of channels in the range from 10 to 30 degrees, d – the diameter of channels in the range from 2 to 4 mm,  $\overline{S}_1$  – the relative area of channels in the range from 0.5 to 1.0 %, H – the depth of the cavity on the side of the load support surface in the range from 0 to 1 mm.

The results of the modelling and experimental research of the aerodynamic factor of conveyor on air cushion with inclined round channels are presented in Fig. 6-8 (the modelling results are shown as a dotted line, the results of the experiment are shown a solid line). As you can see, the differences between the modelled and experimental values of the aerodynamic factor do not exceed 11 %.



**Fig. 6.** The modelled and experimental values of the aerodynamic factor when d = 4 mm,  $\overline{S}_1 = 1$  %, H = 1 mm



**Fig. 7.** The modelled and experimental values of the aerodynamic factor when  $\varphi = 30^{\circ}$ ,  $\overline{S}_1 = 1$  %, H = 1 mm



Fig. 8. The modelled and experimental values of aerodynamic factor when  $\varphi = 30^\circ$ , d = 4 mm, H = 1 mm

The analysis of the graphs, which are presented in Fig. 6-8, allows to conclude that the traction qualities of conveyor on air cushion with inclined round channels increase with increasing incline angle of channels and decrease with increasing diameter of channels and relative square of channel.

#### CONCLUSIONS

1. In the first on the basis of Newton's second law the mathematical model that determines influence of construction parameters on traction qualities of conveyor on an air cushion with inclined round channels is obtained. The mathematical model establishes the functional relationship between incline angle of channels, diameter of channels, relative square of channels and aerodynamic factor of conveyor on an air cushion with inclined round channels.

2. The obtained mathematical model adequately displays the data of the experiment.

The modelling results differ from the results of the experiment for not more than 11 %.

3. The aerodynamic factor which is a criterion for conveyor on an air cushion with inclined round channels increases with increasing incline angle of channels and decreases with increasing diameter of channels and relative square of channel.

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#### ВЛИЯНИЕ ПАРАМЕТРОВ КОНСТРУКЦИИ НА ТЯГОВЫЕ КАЧЕСТВА КОНВЕЙЕРОВ НА ВОЗДУШНОЙ ПОДУШКЕ С НАКЛОННЫМИ КРУГЛЫМИ КАНАЛАМИ

#### Максим Пронин, Евгений Шапран

Аннотация. Получена и экспериментально проверена математическая модель, определяющая влияние параметров конструкции на тяговые качества конвейеров на воздушной подушке с круглыми каналами. Используя наклонными полученную математическую модель, проанализировано влияние параметров конструкции на тяговые качества конвейеров на воздушной подушке с наклонными круглыми каналами. Ключевые слова: конвейер, воздушная

подушка, подъемная сила, тяговая сила

# Temporal evaluation criteria of project-oriented socio-economic and technical systems development

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S u m m a r y : The purpose of the study is to develop a computing method for the calculation of remoteness coefficients for temporal assessment criteria of the socio-economic systems development.

The methodological basis of the research is the methods of graphics simulation, the methods of comparative analysis, and the method of computer simulation.

The main study results are the following. It is shown that if socio-economic systems functioning are under the conditions of turbulent state, then the most preferred assessment criteria of systems development is temporal orders. The temporal order structure was described. The existing procedure of integral developmental assessment calculation, the use of which is limited by the known values of the remoteness coefficients, was also described. The system of graphic models was developed. The conditions for obtaining the formulas for the calculation of remoteness coefficients for the temporal order with any number of elements, were formulated on the basis of the graphic models developed.

K e y w o r d s : developmental criteria, temporal order, integral assessment, remoteness coefficient.

#### INTRODUCTION

The present stage of civilization development is characterized by a high degree of turbulence in all areas of social and technical-organizational systems [2]. In addition, the turbulence in the technical systems creation is observed when the appearance of breakthrough technological solutions can't be embedded in the predicted directions of their development [1, 4, 13].

time. the systems At the same increasingly show signs of uniqueness and focus on getting of some positive results through the creation of a particular product that exhibits unique properties [9]. Such systems can be called project-oriented, regardless of their origin and nature. Under the project-oriented systems we mean the systems whose products have value only for one-off projects that use them for the development of other systems. Such products become a base innovations. which destrov for rapid stereotypes in a particular area of activity and open up new visions in development directions [7].

Turbulence significantly increases uncertainty about the correctness of system motion in the chosen direction. Moreover, it affects the correct choice of direction, which requires constant adjustment when changing system external environment the of performance [14]. This leads to the emergence of new developmental paradigms, one of which is called informative-innovational [3]. Under these conditions, criteria choice problems become significantly more complicated. They reflect the goal of system activity and activity evaluation by these

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criteria [12]. World trends of late 20-30 years show that the turbulence rise will still remain for a long time [8].

### PUBLICATIONS REVIEW

After the global recession happened in the beginning of XXI century the criteria construction methods based on the principle of indicators rate of change tracking were brought into the forefront as opposed to the absolute principle of indicators values achievement by a certain time [5, 25]. At the same time it is possible to monitor the maintenance of preliminary generated and ordered sequence of selected indicators rates of change [17]. These criteria define the indicators temporal order which ensures the development in chosen direction [22, 24].

Different rank correlation coefficients [21] and normalized Hamming distance [6] are used for the integral estimation of deviation scope of the actual temporal order from the normatively adjusted one. However, such criteria are less informative. The main reason is the negligible distance of an indicator in the actual temporal order from its place in the normative temporal order.

eliminate То this drawback, [15] proposes a method of analysis which is based on the registration of the remoteness coefficient value that is preliminary determined. Inherently these coefficients reflect negative impact power for the reduction of the integral estimation as far as index moves off standard location. This method is used to assess the economic security of the innovative project-oriented enterprises [16]. The versatility of this method is defined by the semantic unboundedness of the indicators used, and it allows applying the method to the socio-economic systems development estimation problem, though. Nowadays, this method can only be applied to the temporal order which is comprised of four parameters. This is due to the fact that the remoteness coefficients values are determined only for this amount of parameters for the time being. In practice, their number in the temporal order can be significantly more [10].

# PURPOSE AND RESEARCH PROBLEM STATEMENT

The aim of this research was determined by the practical demand for widening of the application of the method described in [15]. This demand is formulated as a development of temporal assessment criteria of the sustainable development of any socioeconomic systems based on the temporal order with any number of indicators. Moreover, from the perspective of future users it is needed to determine how many elements of the temporal order are enough and why.

#### MAIN SECTION

In general terms temporal order criterion can be represented as follows [23]:

$$h_1^n > h_2^n > \dots > h_j^n > \dots > h_N^n$$
, (1)

where: h is the topics change of certain indicators,

N is the number of indicators of the temporal order,

n is the index, which shows that the temporal order is normative.

An actual temporal order may differ from the normative one by the permutation of its elements.

Possible amount of such permutations D depends on the number of indicators N and is calculated as factorial N:

$$D_N = 1 \cdot 2 \dots (N-1) \cdot N \,. \tag{2}$$

For example, for the temporal order of four components the amount of such combinations can be 24. Some of them may be as follows:

$$h_2 > h_3 > h_4 > h_1$$
, (3)

or: 
$$h_2 > h_3 > h_1 > h_4$$
. (4)

With temporal order increasing for one element  $D_5$ =120, and with N=8,  $D_8$ =40320 already. The value of this indicator shows a high information capacity of temporal order criterion. In practice, this advantage is quite difficult to be used in full.

To take account of the deviation of temporal order actual structure from normative structure the modernized Kendall's coefficient is usually used [19]:

$$K = 1 - \frac{Q}{N(N-1)},\tag{5}$$

where: Q is the number of inversions in the actual temporal order relatively to a normative one.

Depending on the problem that is under study, the Kendall's coefficient may have different meanings. For example, in [20] it is defined as the final assessment of effective management, in [23] as a measure of similarity, and in [15] as the coefficient of economic security.

From the temporal order analysis (Eg. 3, 4) it can be seen that the first order describes the worse development state as compared with the second one. This is due to the fact that in (Eg. 3) the element  $h_1$  is situated farther from its normative position than in (Eg. 4). It is situated on the first place in the normative temporal order. Unfortunately, the (Eg. 5) does not take this fact into account. Therefore, the matrix method which allows taking into account the remoteness coefficients values is used for inversions calculation in [15]. It consists of the following. Primarily it is necessary to populate the actual temporal order matrix by the growth rate values of its indicators per definite period of time. In this matrix the subject and the predicate are normative temporal order. Horizontal rows are populated to the left from the main diagonal. The cells that are below than the diagonal should contain the same values as ones that are higher than the diagonal considering the symmetry properties of the matrix. The following rule is used when filling the matrix. The cells are filled with 1 if indicator's actual growth rate in a row is lower than growth rate in a column. Otherwise the cells are filled with 0. Fig. 1 shows a matrix for temporal orders represented by the (Eg. 3) and (Eg. 4).

	h	$h_2$	<i>h</i> <sub>3</sub>	$h_4$			$h_1$	$h_2$	$h_{3}$	$h_4$
h <sub>1</sub>		1	1	1		$h_1$		1	1	0
$h_2$	1		0	0		$h_2$	1		0	0
h <sub>3</sub>	1	0		0		h <sub>3</sub>	1	0		0
<i>h</i> <sub>4</sub>	1	0	0	Í		$h_4$	0	0	0	
	а				-			b		

**Fig. 1.** The examples of actual temporal order matrixes: a - for actual order (Eg. 3), b - for actual order (Eg. 4)

After populating the matrix of actual temporal indicators the matrix of remoteness coefficients is populated. Fig. 2 shows a matrix for four elements.

		1	2	$j_{M}$	$j_F$
1			0,75	1,35	1,5
2	,	0,75		0,65	1,2
i <sub>M</sub>	,	1,35	0,65		0,55
i <sub>F</sub>		1,5	1,2	0,55	

Fig. 2. Remoteness coefficients values  $a_{ij}$  for N=4

Then these matrixes' cell values with the same indexes are multiplied among themselves, and the multiplication results are substituted into the formula:

$$K = 1 - \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} (Q_{ij} \cdot a_{ij})}{N(N-1)}.$$
 (6)

As we can seen, the numerator of the second component of this formula takes into account not only the number of inversions, but also the influence of elements remoteness in the actual temporal order from their normative positions.

For today the (Eg. 6) is applicable for N=4, since only for such value of the elements of the temporal order the coefficients  $a_{ii}$  are known.

Let's contemplate the problem of determining of these coefficients for any N value. We define the matrix (Fig. 2) as an initial one. For the indexes i and j the following sub-indexes are used to define an initial matrix's elements:

M is the middle element,

F is the last element.

We assume that the increase in the number of elements in a temporal order to N shifts remoteness coefficient value of the original matrix so that:

$$j_M = j_{N/2+1}, \quad i_F = i_N.$$
 (7)

On this basis, six elements of the initial matrix are arranged in matrix cells  $N \times N$ , as shown in Fig. 3.



Fig. 3. The arrangement of elements from the initial matrix for the matrix size  $N \times N$ 

Assume that in matrix  $N \times N$  the values  $a_{ij}$  vary linearly between any two elements of the basic matrix which are marked as ellipses in Fig. 3. Then to find the values  $a_{ij}$  for each  $N \times N$  matrix cell we mark out four triangular areas above the main diagonal. These areas intersect by cathetus (I and II, III and IV) and by hypotenuse (II and III) (Fig. 3.). Areas

intersections determine the equality of the elements values in neighboring areas on conditions that their indexes coincide in the system shown in Fig. 4.



Fig. 4. Equality condition for the elements in neighboring areas

Such area selection fits the principle of harmonization of different interaction of separations [18].

A single system of local indexes, the same for all four areas, was used when determining matching conditions. It is presented in Fig. 5.



Fig. 5. A system of local indexes for the examined area

Then, local indexes can be expressed through the indexes of the main matrix for each triangular area (Fig. 6).

Area	Area	Local indexes				
Nº	form	i,	$i_f$	$j_s$	$j_f$	
I	$\bigtriangledown$	1	i <sub>M</sub>	2	$\dot{J}_M$	
11		1	i <sub>M</sub>	$j_M$	$j_F$	
111	$\Box$	1	i <sub>M</sub>	$j_M$	$\dot{J}_F$	
IV		i <sub>M</sub>	i <sub>F</sub>	$j_M$	$j_F$	

**Fig. 6.** The correspondence between local indexes and main matrix indexes of for the selected areas

Let's study are model given on Fig. 5. In this model  $a_{ij}$  values for every element can be determined using the formula:

$$a_{ij} = a_{i,j_{fi}} - (j_f - j)\Delta_j,$$
 (8)

where:  $\Delta_j$  is the step between elements values in *i*-th row.

This formula provides line-by-line calculations and filling the matrix, i.e. for i = const, and j = var.

The model in Fig. 5 shows that the number of elements in a row for different i is not equal. It can be calculated as:

$$m_j = (j_f - j_s) - (i - i_s).$$
 (9)

Accordingly, the step between elements values in *i*-th row will be calculated as:

$$\Delta_j = \frac{a_{i,j_{fi}} - a_{i,j_{si}}}{(j_f - j_s) - (i - i_s)}.$$
 (10)

In this formula, the components included in the numerator depend on the i values.

Using analogical inference with (Eg. 8) the first component can be calculated from the following dependency:

$$a_{i,j_{fi}} = a_{i_s,j_f} - (i_s - i)\Delta_i,$$
 (11)

where: 
$$\Delta_i = \frac{a_{i_s, j_f} - a_{i_f, j_f}}{i_f - i_s}$$
, (12)

 $\Delta_i$  value determines the step between elements values in  $j_f$  column.

The second component is defined as:

$$a_{i,j_{si}} = a_{i_s,j_s} - (i_s - i)\Delta_{is},$$
 (13)

where: 
$$\Delta_{is} = \frac{a_{i_s, j_s} - a_{i_f, j_f}}{i_f - i_s}$$
. (14)

 $\Delta_{is}$  value determines the increment between elements  $a_{is,js}$  and  $a_{if,jf}$ , which are parallel to the main diagonal.

Having analyzed the formulas (Eg. 8) -(Eg. 14) we can see that all incoming parameters are determined by the elements values of the main matrix. They depend on what triangular area is examined. Depending on that, local indexes values (Fig. 6) and appropriate elements of the main matrix are chosen. The formulas received made the basis of a computer program for the calculation of remoteness coefficients for N=4-12, that was in MS Excel development designed framework. The scheme of stage analysis and synthesis of complex objects was used in calculation algorithm development [11].

The remoteness coefficients values for N=4 (Fig. 2), the table of correspondence between local indexes and main matrix indexes (Fig. 6) and the number of temporal order elements N were used as input data. The programming algorithm provides the automatically selection of borders of four triangular areas and the validity check of the arrangement of initial matrix elements in the  $N \times N$  matrix. Fig. 7 shows a sample of the calculation of remoteness coefficients for N=10.

It is obvious that the arrangement of initial matrix elements (in bold) corresponds to the planned arrangement (Fig. 3).

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0,75	0,90	1,05	1,20	1,35	1,39	1,43	1,46	1,50	0	0
2	0,75	0	0,73	0,88	1,03	1,18	1,21	1,25	1,29	1,43	0	0
3	0,90	0,73	0	0,70	0,85	1,00	1,04	1,08	1,21	1,35	0	0
4	1,05	0,88	0,70	0	0,68	0,83	0,86	1,00	1,14	1,28	0	0
5	1,20	1,03	0,85	0,68	0	0,65	0,79	0,93	1,06	1,20	0	0
6	1,35	1,18	1,00	0,83	0,65	0	0,63	0,76	0,90	1,04	0	0
7	1,39	1,21	1,04	0,86	0,79	0,63	0	0,60	0,74	0,88	0	0
8	1,43	1,25	1,08	1,00	0,93	0,76	0,60	0	0,58	0,71	0	0
9	1,46	1,29	1,21	1,14	1,06	0,90	0,74	0,58	0	0,55	0	0
10	1,50	1,43	1,35	1,28	1,20	1,04	0,88	0,71	0,55	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 7. Remoteness coefficients values  $a_{ii}$  for N=10



Fig. 8. Cell indexes values for the elements  $a_{1,2}$ ,  $a_{1,j_M}$ ,  $a_{1,j_F}$  arrangement in the first matrixes rows for N = 4-12

The processing of calculation results for N=4-12 confirms that in all cases the elements  $a_{1,2}$ =0,75,  $a_{1,j_M}$ =1,35,  $a_{1,j_F}$ =1,5 from the first row are situated in the cells with the indexes 2,  $j_{N/2+1}$ ,  $j_N$  accordingly (Fig. 8).

A similar result is obtained for the elements  $a_{1,j_F} = 1,5,$   $a_{i_M,j_F} = 1,2,$   $a_{i_F,j_F} = 0,55$  that are located in the last column of the matrixes (Fig. 9).

To answer the question about the rational number of temporal order elements the number of computer experiments was done. These experiments used the actual temporal orders where all alternate scrambling only belonged to one of the four selected areas (Fig. 3). For each of these cases and different N values, the coefficient K was calculated using the (Eg. 6). Fig. 10,a shows the calculation results.

			N							
i		. 12	10	8	б	4				
1	→ ⟨	1,50	••••							
2		1,44	1,50	•						
		1,38	1,43	1,50	••••					
		1,32	1,35	1,40	1,50	••••				
		1,26	1,28	1,30	1,35	1,50				
i <sub>N/2</sub>	→[	1,20	1,20	1,20	1,20	1,20				
		1,07	1,04	0,98	0,88*	0,55				
		0,94	0,88	0,77	0,55					
		0,81	0,71	0,55	******					
$\dot{l}_{N-2}$		0,68	0,55	******						
<i>i</i> <sub>N-1</sub>	<b>→</b>	0,55	******							

Fig. 9. Cell indexes values for the elements  $a_{1,j_F}$ ,  $a_{i_M,j_F}$ ,  $a_{i_F,j_F}$  arrangement in the last matrixes columns for N =4-12
As it can be seen, regardless of N the smallest K value appears when permutations take place in the areas II and III. And the biggest K value is observed in the area IV.

The calculation of coefficient K variation by areas with K increase showed the following. With N increasing from N=8 to N=10, the K variation doesn't exceed 5% (Fig. 10,b). Therefore, further increasing of the number of temporal order elements is not reasonable.

N空	N									
space	4	6	8	10	12					
II	0,42	0,53	0,58	0,61	0,63					
	0,44	0,55	0,6	0,63	0,66					
I	0,54	0,63	0,67	0,69	0,71					
IV	0,60	0,68	0,73	0,73	0,75					

		a		
N≌			N	
space	4-6	6-8	8-10	10-12
=	20,8	8,6	4,9	3,2
=	20,0	8,3	4,8	4,5
_	14,3	6,0	2,9	2,8
IV	11,8	6,8	0,0	2,7
		h		

Fig. 10. Coefficient K values (a) and its relative percentage %% variation (b) for different areas and N values

## CONCLUSIONS

1. Based on the assessment of the current state of development processes, the presence of high turbulence was established not only in social and technical-organizational the systems, but also in creating of technical systems. It was proposed to define the last mentioned systems as project-oriented, because the unique product of these systems is demanded only special projects, which are, in their turn, used for the development of other systems.

2. It was shown that such conditions brought the methods of development test construction into the foreground. These methods are based on monitoring of the change rates of certain indicators. At the same time, the normative temporal order of their succession should be pre-determined.

3. An insufficient adequacy of integral criterion scores was specified. These scores were calculated excluding the actual index location compared with the normative order. The technique that eliminates this drawback by using remoteness coefficients, which values are strictly defined, was found. However, this technique is applicable only for the temporal order which consists of four indicators. Although in practice, a significantly great number of indicators are used.

4. A calculation method for remoteness coefficients for any number of indicators in the temporal order was proposed. . It is based on maintaining the order of remoteness coefficients values, which are used in the present method, in certain places. This was achieved through the use of a special approach to the selection of matrix elements, which has the dimension of the temporal order, and the introduction of a universal system of local indexes for these areas.

5. The computer experiment that was conducted shows the versatility of the method developed. Furthermore, it was proved that from a practical standpoint the temporal order of eight indicators is a sufficient one. A further increasing in the number of indicators may change the value of the integral criterion of not more than 2.5%.

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#### ТЕМПОРАЛЬНЫЕ КРИТЕРИИ ОЦЕНКИ РАЗВИТИЯ ПРОЕКТНО-ОРИЕНТИРОВАННЫХ СОЦИАЛЬНО-ЭКОНОМИЧЕСКИХ И ТЕХНИЧЕСКИХ СИСТЕМ

#### Валентин Рач, Масауд Султан

Аннотация. Показано, что В условиях турбулентного состояния функционирования социально-экономических систем наиболее предпочтительными критерии оценки их развития темперальные являются порядки. Описана структура темперального порядка и существующая методика расчета интегральной оценки развития, применение которой ограничено известными значениями коэффициентов удаленности. Разработана система графических моделей, на основании которых сформулированы условия получения формул для расчета коэффициентов удаленности для темпорального порядка с любым количеством элементов.

Ключевые слова: критерии развития, темпоральный порядок, интегральная оценка, коэффициент удаленности

# Economic-mathematical modeling of rational water use and minimization engineering enterprise's negative impact on the environment

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S u m m a r y. This article applies to application of economic-mathematical modeling for eco-directional control for industrial enterprises. Research was conducted on the example of the engineering enterprise "Luganskteplovoz" in part of ensuring efficient use of water in industrial manufacturing and minimize the negative impact of enterprise activities on the environment. Mathematical model of finding the economic optimum of contaminated water cleaning in carrying out enterprise production activity was constructed.

Key words: industrial enterprise, water supply of manufacturing, unsustainable natural resource use, environmental pollution, economic and environmental damages, economic- mathematical modeling, eco-directional control.

## INTRODUCTION

Industrial enterprises need significant water supply to function effectively. Water consumption of domestic production is among the highest in the world today, it is about 0.3 m3 per UAH of finished product. Actuality of the theme caused by the deepening problem of unsustainable natural resources use, leading to environmental pollution and causes significant economic and environmental damages. Major number of Ukraine's industrial enterprises were built in the USSR and most of them are highly resource-intensive, with depreciation of equipment and production obsolete or ineffective filtration technologies emissions and discharges [2, 6, 7, 11]. In such conditions the entity striving to make a profit may be followed by causing irreparable environmental damage, exceeding the standards of resources use, which is a violation of existing legislation. Therefore, environmental particularly important becomes the searching the optimal level of cleaning pollution that is manufacturing formed during process. Considerable attention should be paid to ecological and economic impact assessment of active industrial enterprises in order to regulate manufacturing processes and organizational measures to minimize their destructive effects.

## OBJECT, SUBJECT AND AIM OF RESEARCH

The object of the research is manufacturing processes on industrial enterprise. The subject is the influence of manufacturing processes on the environment. The main aim of the research is the implementation of environmentally oriented enterprise management to minimize the negative influence of its activities on the environment and development of approaches to the regulation of water use in the industrial production.

## **RESULTS OF RESEARCH**

Diversified economic complex established in Ukraine requires the use of many natural resources. One of the most important natural resource that defines the location of the productive forces is water, and very often it is also the means of production. Industrial enterprises need significant water supply [20]. The main impact of water use on water resources is conditioned by rotation-free water intake and discharging pollutants into water bodies. Therefore it is especially important to research the influence of manufacturing processes on water bodies in order to maintain optimal water environmental indicators and reduce ecological-economic damage from the industry impact on the environment. Industry represents 58% of the total volume of contaminated wastewater. The main sources of water pollution are enterprises that are pulp and paper industry, chemical, production of coke, petroleum, mining iron metallurgy ore. coal. industries and mechanical engineering. For example, Fig.1 shows how the volume of wastewater discharging is distributed by branches of economy Lugansk region [1].

Engineering enterprises' runoffs in the Luhansk region have significant influence on surface water bodies. The causes of pollution of water resources are the lack of wastewater treatment before its discharging into rivers or sewage system. Wastewater etching and plating plants polluted by petroleum products, sulfates, chlorides, suspended solids, cyanide, nitrogen compounds, salts of iron, copper, chromium, zinc, nickel, molybdenum, phosphorus, cadmium [1, 5, 8]. Heavy metals, radionuclides and other solid waste aren't disposed of or re-processed and thereby cause harmful effects on the environment [5, 9].



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**Fig. 1.** The volume of wastewater discharging by branches of industry Lugansk region:



One of the industrial enterprises, working in mechanical engineering and provides wastewater discharges to the river Lugan is public joint stock company "Luganskteplovoz". Research was conducted on this enterprise. "Luganskteplovoz" as the enterprise with significant production volume, according to the law of Ukraine "On Environmental Protection" [10] and other legal documents in the sphere of environment should closely monitor the processes that the environment. Department of affect environmental protection is division dealing with industrial area environmental monitoring [12, 19].

Manufacturing processes of machinebuilding enterprises are characterized by high levels of environmental pollution. These processes include: in-plant energy production and other processes that involve combustion of fuel, foundry production, metal working structures and components, welding production, refinishing products. At the plant in order to reduce concentration of pollutants wastewater treatment plants and installation of water treatment are set. They are used before discharging wastewater into water bodies. The main type of industrial wastewater treatment facilities is mechanical oil traps. Mechanical cleaning allows to allocate 70-80% insoluble impurities from industrial waste water.

Average values for each of the pollutants in wastewater "Luganskteplovoz" and their comparison with the approved standards maximum permissible discharge (MPD) are shown in Table. 1 [13]. Data table shows that results of 11, 14 water outlets and rotating stop valve water outlet exceed the maximum permissible discharge of pollutants. This can demonstrate that there is a need to establish additional treatment facilities at some water outlet or necessity manufacturing processes redesign to reduce the concentration of pollutants in the water.

	water outlet 4		V	vater outlet	9	water outlet 11		water outlet 12				
	actual g/year	MPD	excess	actual g/year	MPD	excess	actual g/year	MPD	excess	actual g/year	MPD	excess
suspended matter	41,6	90	-	157,08	115,5	41,58	1144	924	220	820	1982,5	-
mineralization	2641,6	5400	-	8085	6930	1155	93184	63000	30184	36660	118959	-
nitrogen	0,5	1,404	-	1,8018	1,8018	-	20,28	16,38	3,9	8,04	31,72	-
nitrity	0,195	0,54	-	1,155	1,155	-	18,2	14,7	3,5	2	11,895	-
nitrates	68,9	162	-	184,8	184,8	-	1560	1470	90	700	2775,5	-
sulfates	67,3	1800	-	2310	2310	-	26000	21000	5000	10600	39650	-
chlorides	5,81	1260	-	1617	1617	-	18200	14700	3500	7600	27755	-
oil	0,381	1,08	-	7,67	1,386	6,284	15,6	12,6	3	6,03	23,79	-
phosphates	4,445	12,6	-	9,24	9,24	-	104	84	20	40,2	158,6	-
iron	8,5	1,08	7,42	1,386	1,386	-	15,6	12,6	3	7	23,79	-
zinc	0,91	2,52	-	5,36	4,62	0,74	51,87	42	9,87	22	79,3	-
copper	0,045	0,126	-	0,1386	0,1386	-	1,716	1,386	0,33	0,66	2,6169	-
nickel	0,065	0,18	-	0,2772	0,2772	-	5,187	4,2	0,987	1	3,965	-
aluminum	0,381	1,08	-	1,57	1,385	0,185	13	10,5	2,5	4	15,86	-
chrome	0,0127	0,036	-	0,05544	0,05544	-	8,32	6,72	1,6	0,4	1,586	-
	wat	er outlet	13	water outlet 14			water outlet 15			water outlet rotating stop valve		
	actual g/year	MPD	excess	actual g/year	MPD	excess	actual g/year	MPD	excess	actual g/year	MPD	excess
suspended matter	1164,8	193	971,8	7426	1193,25	6232,75	5621	3075	2546	870	633,25	236,75
mineralization	11200	44580	-	90522	76368	14154	64970	184500	-	50750	37995	12755
nitrogen	57,6	15,4	42,2	470	9,46	460,54	18,25	61,5	-	87,21	50,66	36,55
nitrity	1,6	1,93	-	9,4	0,946	8,454	5,5	18,45	-	6,3	17,731	-
nitrates	128,6	154,4	-	940	954,6	-	1168	4305	-	1305	1139,9	165,15
sulfates	2015											
	3215	3860	-	25615	23865	1750	18250	61500	-	14535	12665	1870
chlorides	3215 2250,5	3860 2701	-	25615 18800	23865 16705,5	1750 2094,5	18250 129575	61500 43050	- 86525	14535 10175	12665 8865,5	1870 1309
chlorides oil	3215 2250,5 8,7	3860 2701 2,316	- - 6,384	25615 18800 80,37	23865 16705,5 14,32	1750 2094,5 66,05	18250 129575 57,305	61500 43050 36,9	- 86525 20,405	14535 10175 8,721	12665 8865,5 7,6	1870 1309 1,121
chlorides oil phosphates	2250,5 8,7 12,86	3860 2701 2,316 15,44	- - 6,384 -	25615 18800 80,37 94	23865 16705,5 14,32 95,46	1750 2094,5 66,05 -	18250 129575 57,305 73	61500 43050 36,9 246	- 86525 20,405 -	14535 10175 8,721 58,14	12665 8865,5 7,6 50,66	1870 1309 1,121 7,48
chlorides oil phosphates iron	3215 2250,5 8,7 12,86 33,92	3860 2701 2,316 15,44 3,86	- - 6,384 - 30,06	25615 18800 80,37 94 14,1	23865 16705,5 14,32 95,46 14,32	1750 2094,5 66,05 - -	18250 129575 57,305 73 10,95	61500 43050 36,9 246 36,9	- 86525 20,405 - -	14535 10175 8,721 58,14 29,07	12665 8865,5 7,6 50,66 12,665	1870 1309 1,121 7,48 16,405
chlorides oil phosphates iron zinc	3213 2250,5 8,7 12,86 33,92 7,94	3860 2701 2,316 15,44 3,86 7,72	- 6,384 - 30,06 0,22	25615 18800 80,37 94 14,1 51,7	23865 16705,5 14,32 95,46 14,32 47,73	1750 2094,5 66,05 - - 3,97	18250 129575 57,305 73 10,95 40,15	61500 43050 36,9 246 36,9 123	- 86525 20,405 - - -	14535 10175 8,721 58,14 29,07 44,95	12665 8865,5 7,6 50,66 12,665 25,33	1870 1309 1,121 7,48 16,405 19,62
chlorides oil phosphates iron zinc copper	3213 2250,5 8,7 12,86 33,92 7,94 0,41	3860 2701 2,316 15,44 3,86 7,72 0,49	- 6,384 - 30,06 0,22 -	25615 18800 80,37 94 14,1 51,7 1,974	23865 16705,5 14,32 95,46 14,32 47,73 2,005	1750 2094,5 66,05 - - 3,97 -	18250 129575 57,305 73 10,95 40,15 1,314	61500 43050 36,9 246 36,9 123 4,428	- 86525 20,405 - - - -	14535 10175 8,721 58,14 29,07 44,95 0,899	12665 8865,5 7,6 50,66 12,665 25,33 0,7852	1870 1309 1,121 7,48 16,405 19,62 0,1138
chlorides oil phosphates iron zinc copper nickel	3213 2250,5 8,7 12,86 33,92 7,94 0,41 0,256	3860           2701           2,316           15,44           3,86           7,72           0,49           0,31	- - 6,384 - 30,06 0,22 - -	25615 18800 80,37 94 14,1 51,7 1,974 2,82	23865 16705,5 14,32 95,46 14,32 47,73 2,005 2,864	1750 2094,5 66,05 - - 3,97 - -	18250           129575           57,305           73           10,95           40,15           1,314           1,387	61500 43050 36,9 246 36,9 123 4,428 4,674	- 86525 20,405 - - - - -	14535 10175 8,721 58,14 29,07 44,95 0,899 0,63	12665 8865,5 7,6 50,66 12,665 25,33 0,7852 1,7731	1870 1309 1,121 7,48 16,405 19,62 0,1138 -
chlorides oil phosphates iron zinc copper nickel aluminum	3213 2250,5 8,7 12,86 33,92 7,94 0,41 0,256 1,8	3860 2701 2,316 15,44 3,86 7,72 0,49 0,31 2,162	- 6,384 - 30,06 0,22 - -	25615 18800 80,37 94 14,1 51,7 1,974 2,82 41,36	23865 16705,5 14,32 95,46 14,32 47,73 2,005 2,864 23,865	1750 2094,5 66,05 - - 3,97 - 17,495	18250           129575           57,305           73           10,95           40,15           1,314           1,387           29,2	61500 43050 36,9 246 36,9 123 4,428 4,674 61,5	- 86525 20,405 - - - - - -	14535 10175 8,721 58,14 29,07 44,95 0,899 0,63 6,96	12665 8865,5 7,6 50,66 12,665 25,33 0,7852 1,7731 6,08	1870 1309 1,121 7,48 16,405 19,62 0,1138 - 0,88

Table 1. Comparison of actual discharges with the standards MPD

The enterprises economic performance substantially depends on the value of the damages to the environment [15 - 18]. Economic-mathematical models construction provides an opportunity to give assessment of industrial enterprise influence on both economically and environmental indexes. The enterprise's management will be able to regulate the manufacturing processes in a way that will be optimal economic development level achieved with the lowest possible influence on environment based on the obtained results by model.

Suppose that there is one source that empty one type of pollutant in the water body.

Introduce the notation:

D – production volume, (units),

S(D) – volume of polluted with D – production volume, (mg/l),

Z(X) – the cost of cleaning X-volume of pollution, where X takes values  $0 \le X \le S(D)$ , (conventional money units),

U(S-X) – costs formed by dumping (S-X)- pollution volume (conventional money units),

X - volume of pollution cleared, (mg/l or mg/dm3).

The total volume of contaminated water that enterprise forms may partially or completely cleaned by treatment facilities.

The enterprise can't cleanse more pollution than the total volume of contaminated water S, which is shown as a vertical line in Fig. 2. Hence, the obtained restriction  $0 < X \le S$  (D).



**Fig. 2.** The volume of treated water X in the total discharges S

The legislation sets a certain level of pollution, which may include waste water, which does not lead to violations of environmental and human health, it is call maximum allowable concentration (MAC) [14]. Let's put allowed level of pollution as of contaminated VMAC. The volume wastewater that needs mandatory clearing to achieve MAC standards, marked as XMAC, from this XMAC=S-VMAC. If D-production volume in the enterprise is high, the wastewater formation will grow. This would increase pollution in wastewater discharges and harmful substances possibly greater than set level V<sub>MAC</sub> (Fig. 3).



Fig. 3. Volume of pollutants that exceeds MAC level

In order to achieve MAC standards mandatory minimum volume X<sub>MAC</sub> of polluting substances should be cleaned. Also, it is necessary to predict the additional volume of clearance in the range of  $(X_{MAC}, X_{opt})$ . The optimum level of cleaning  $X_{opt}$  is within  $X_{MAC} \le X_{opt} \le S(D)$ . Value  $X_{opt}$  reduces their negative impact on the environment and the cost of dumping pollutants into the pond U(S-X). Fee for violating MAC can be increased by 5 times maximum according to Ukrainian legislation (or gradually from 1 to 5) [3, 4]. If at the enterprise there is no limits of emissions and discharges of pollutants approved in the prescribed manner, fee is charged as per above-limit discharges [12].

Thus, for each production volume D applies follows dependency (Fig. 4). Conventionally, it is possible to consider given dependencies for fixed production volume D, which further will be denoted in the calculation as upper index.



**Fig. 4.** Graphic representation of economicmathematical model of achievement standards MAC and economic optimum pollution

Increase X treated wastewater will reduce the cost U=S-X of dumping pollutants into the water bodies. Along with the reduction of costs formed by dumping (S-X)-pollution volume, there is an increase costs Z for wastewater treatment.

Total costs are formed from costs of cleaning and the cost of dumping pollutants, note them as  $W^{D}(X)$  and it can mathematically expressed as:

$$W^{D}(X) = Z^{D}(X) + U^{D}(S - X).$$

Minimum of function (Fig. 4) corresponds to a point that results in the condition:

$$\frac{\partial W}{\partial X} = 0$$

Mathematical model was built for regulation the interaction of enterprises with the environment, taking into account the economic interests of the enterprise. This model may be the basis for tracking the achievement of the eco-management system on an industrial enterprise. The purpose of modeling is searching optimal volume cleaning  $X_{opt}$  at which the minimum total cost W, related with pollution and the costs of cleanup.

Value of X pollution cleaned is limited technical capabilities of installed treatment plants, mark it as  $X_{TC}$ .

By giving different values of production volumes the proposed model can be used in dynamics. For management of the enterprise it will enable to determine the production volume in which it receives economic profit and has minimum possible negative influence on the environment.

Calculations were made with the understanding that the waste water can be treated only of oil by oil trap, so pollution means the oil content.

Legally allowed to dump oil into the reservoir equal to 0.2008 tonnes per annum [13]. If the volume of polluted more than the allowed amount (equal 0.2008 MAC) than environmental payments increases depending on the excess, up to 5 times [4].

According to statistical data of enterprise dependence between waste formation and production volume was found. It's like polynomial y = -6E-06x2 + 0.0037x + 0.1058. Even with a minimum production volume a certain volume of pollution will be formed.

Searching for the optimal level of contaminated wastewater enterprise and visualization of results software package MATLAB [21] applied.

Approbation results of economicmathematical model for "Luganskteplovoza" are shown in Fig. 5. Thus, the production of 40 units of output produced relatively few pollutants. The company still has a reserve of polluted because statutory limit is not exceeded. In this case, economically this volume of pollution dump to water bodies without a clearance. The company pays a regular tax rate, cost is about 1200 UAH (Fig. 5a).











a – the production of 40 units of output,

b - the production of 110 units of output,

c - the production of 168 units of output,

d – the production of 225 units of output

	– limit possible discharge (dotted external),
	- technical cleaning capability (dotted internal),
- total cost (solid upper),	$*$ – searching optimal volume cleaning $X_{opt}$

For typical in recent years production volume of 110 units and existing treatment plant capacity the optimum level of cleaning is 0.24 tons, 0.57 tons of pollution formed. In this situation, enterprise pays a tax rate increased 2-fold, the total cost is 4200 UAH. (Fig. 5b). Situation with increased production volumes modeled. Optimum approaching to the border treatment plants technological cleaning capabilities (Fig. 5c). With an increase in production to 225 units optimal cleaning is 0.49 tpa, but the this optimum is

out of reach because of treatment plants technological cleaning capabilities limited opportunities in 0.48 tons. Enterprise pays ecological tax increased 3 times, total costs are 7500 UAH (Fig. 5d). It needs additional installation or upgrade existing treatment facilities.

With production volume to 40 units of output for enterprise it economically does not cleaning the pollutants because of their MAC standards allowable concentration (Fig. 6).



**Fig. 6.** The dependence of the economically optimal level of pollutants cleaning X and production volume D



**Fig. 7.** Three-dimensional graphics costs for water use of the enterprise depending on production volume and cleansing of pollution

It can be used in planning environmental protection measures at increasing production

capacity to identify the need for further purification formed pollution.

In Fig. 7 surface, which characterizes the change in costs on water use is shown.

From an environmental and economic point of view optimal is such volume pollution cleansing that allows pay for regular tax rate, it is form the first chute surface. The cost of treatment is higher than the cost of polluted, making economically profitable to pay increasing environmental tax (2nd and 3rd chute surface) worsening state of the environment than to install a powerful and wastewater treatment system.

#### CONCLUSIONS

1. Economic-mathematical model building and its program realization by means of MATLAB had given simulation opportunity of dependence of costs of wastewater treatment and planning production volume, taking into account the existing treatment facilities technical capabilities, allowable discharge of pollutants and environmental taxes.

2. Results of research can be used for strategic and operational ecologico-economic management in order to exercise ecodirectional control at industrial enterprise.

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#### ЭКОНОМИКО-МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ РАЦИОНАЛЬНОГО ВОДОПОЛЬЗОВАНИЯ И МИНИМИЗАЦИИ НЕГАТИВНОГО ВЛИЯНИЯ МАШИНОСТРОИТЕЛЬНОГО ПРЕДПРИЯТИЯ НА ОКРУЖАЮЩУЮ СРЕДУ

#### Султан Рамазанов, Анна Воронова

Аннотация. В статье рассматривается применения экономико-математического моделирования лпя обеспечения экологически направленного управления для промышленных предприятий. Исследование проводилось машиностроительного предприятия на примере "Лугансктепловоз" в части обеспечения эффективного водопользования в сфере промышленного производства и минимизации негативного влияния его деятельности на природную среду. Построена экономико-математическая модель поиска экономического оптимума очистки загрязнений водных ресурсов при осуществлении производственной деятельности предприятием.

Ключевые слова: промышленное предприятие, водообеспечение производства, нерациональное природопользование, загрязнение окружающей среды, экономические и экологические убытки, экономикоматематическое моделирование, экологически направленное управление.

## The analysis of machine embroidery stitches types classification

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S u m m a r y : The article deals with the problems of the lack of uniformity in machine computer embroidery terminology, as well as the existing classification of types of embroidery stitches that are based on the basis of specific software tools of embroidery editors. There have been analyzed both their advantages and disadvantages. There have been defined the basic types of machine computer embroidery.

Key words: machine embroidery, stitches type, classification.

## INTRODUCTION

Currently, Ukraine has a small amount of embroidery businesses compared with Western Europe, North America and Asia, where the industry is thriving in small and medium sized businesses. However, the number of such enterprises is rapidly spreading. Embroidery extensively uses computer technology, Internet technology for data transmission, which, undoubtedly, is quite comfortable. But at the same time, enterprises point out the insufficient amount of information in this area.

The purpose of this article is overview existing classifications of types stitches embroidery.

Object of study – the process of classification a type stitches machine computer embroidery.

The subject of the study – the type of embroidery stitches.

The majority of Ukrainian publications that are devoted directly to the issues of machine embroidery, are usually represented by advertising publications and interviews of small embroidery firms and distribution companies of foreign corporations. Since 2010, the most comprehensive source have been documentation translations of foreign software and materials from organizations web sites that are engaged in machine embroidery. Auxiliary barriers to information are related with the desire of organizations to preserve trade secrets of domestic production developments.

Nowadays there is a number of overseas embroidery companies associations, there is issued periodical literature and there work special schools, there are organized international conference, as well as online conferences on machine embroidery. Thus, among the foreign periodicals there should be noted Eurostitch magazine, Printwear, Stitch & Print, Embroidery, Stitches magazine, Designs in machine embroidery, Creative machine embroidery magazine and others.

#### **OBJECTS AND PROBLEMS**

Among the foreign authors, who are covering embroidery machine issues, there are: B. Geer, J. Lamb, B. Start, H. Hart Momsen, D. Jones and others, whose articles are widely published in periodicals and online publications. Thus, one of the pioneers in the field of machine embroidery - Barry Start distinguishes in his works the following types of stitches: step, cross, satin, stem, star [3]. The peculiarity of his classification is the commitment to outdated machine embroidery design, that is: hand position design of each puncture ("a stitch is a stitch punching"), the use of graphic tablets and perforation, which, in our opinion, is a disadvantage.

In his research, «You can digitize» [11] James M. Lamb is studying embroidery programs design based on the opportunities and software editor of computer embroidery Pulse Signature (Tajima DG / ML). The author suggests the description of stitches types used in the editor (Fig. 1).

The peculiarity of his classification is binding to the ways of setting up a certain stitch type using specific software tools of embroidery editor Pulse Signature (Talma DG / ML). V. Tikhomirov (LLC "SysTech", Russia) in the description of embroidery editor GR3 [27] identifies the following types of stitches as half-stitch, line, zigzag, tatami etc. The classification of V. Tikhomirov is also based on a software tool for building stitching used in the GR3 editor.

Chernenko's work [3] D. divides embroidery stitches (or stitches overfilling) into three basic types: the line, glad' and satin. His classification is based on the completed form of stitch fillings that convey the basic elements of artistic composition - contours, lines, spots (Fig. 2). With this approach, as claimed by D. Chernenko [2, 3], there are considered the geometric and visual properties of stitch fillings, regargless of the program editor and algorithms by which they were created. However, in our opinion, this classification has many disadvantages, which will be touched upon further.

In the embroidery design program editor "Urfinus" (LLC "Dzhussoft", Russia) [18] types of stitches are classified as simple and complex objects (Fig. 3). The peculiarity of this classification is that instead of the stitch type the authors use the term "object". Classification is based on the capabilities of the software editors "Urfinus".



Fig. 1. Stitches types classification (J. Lamb)



Fig. 2. Stitch fillings classification [3]: a – line, b – satin, c – glad'



Fig. 3. Stitches types classification of "Urfinus" editor (LLC "Dzhussoft")

Since the task of the embroidery design programming is the distribution of a given pattern into separate filling areas, and different areas tend to require different types of filling, which differ in density and direction of filling, in the picture of filling etc., then the object is a piece of the program saved in a special format (\*.urf) as a set of nodal points that describe the shape of the object, and list their properties that define the method of object filling [18]. The disadvantage is the lack of classification such term as type of stitch.

Among the domestic companies the should be pointed out Ltd. "Epsima, NPP" (Zhytomyr, Ukraine) [12], which classifies the stitches on the principle that is based on the traditional manual seams. During their seminars on technological foundations of machine embroidery, specialists the distinguish only two basic types of stitches with modifications (Fig. 4).



Fig. 4. Stitch types classification, based on the materials of Ltd. "Epsima, NPP"



Fig. 5. Stitch types classification (M. Belova): a - hand stitch, b - run stitch, c - satin, d - tatami

In his article [1] M. Belova suggestss to classify machine embroidery stitches as four basic types (Fig. 5): manual stitch, run/walk stitch, satin (possible titles: smooth surface, column stitch, satin stitch, satin path, etc.) and tatami (possible titles: filling, step, fill, complex fill, ceeding stitch).

Famous in the west digitizer H. Hart Momsen in his research [15] suggest classifying embroidery stitches (stitch objects) into two types: simple and satin stitch (glad'). Unlike M. Belova, H. Hart Momsen believes that hand stitching is a simple stitch in which all the stitches are defined according the location and length by the programmer, not governed by the software, so may not be considered typical. Fill is also not considered an independent stitch: it is seen as a constellation of many straight stitches.

#### **RESULTS AND DISCUSSION**

## *Types stitches of machine embroidery. Universal classification*

As of today there is a lot of embroidery software: Pe-design, Urfinus, Ces\_2000, Eos3, Embird Studio, Wilcom ES, Tajima DG / ML by Pulse Ambassador and others [19, 23-25]. Thus, one of the most versatile machine embroidery editors at present is considered Wilcom ES (Head Office – Sydney, Australia). The authors-developers of the program [7] classify all machine stitches into two types: outlines and fill (Fig. 6).



Fig. 6. Stitch types classification of Wilcom ES editor

Traditionally, there believed to be only three types of machine embroidery: a simple stitch (Run), satin (glad') and fill (Fill) [1]. Each of them should be studied separately further.

Run (simple stitch, stitch, straight stitch, running stitch; walk stitch) – number of single stitches along the line. Needle punctures occur in sequential order (Fig. 2a, 7). Almost each of the reviewed classifications have this type of stitch. Its properties are fully set out in the given research [3].



Fig. 7. Simple stitch (Run)

If with a simple stitch almost everything is simple, with the following types of embroidery stitches there might occur some complications. For example, satin (satin stitch, column stitch, satin stitch, satin path, steal, etc.) is considered by D. Chernenko [3] a tight zigzag (Fig. 2b). S. Fedorov [7] notes that the name "Satin" is derived from the name of a particularly smooth fabric weave. Like fabric, "Satin" stitches smoothly fill some element of embroidery from one edge to another edge of the form (fig. 8a). Zigzag stitches are similar with "Satin", but unlike this one, every stitch is done with an inclination towards the base (Fig. 8b).

Thus, we can conclude that satin and zigzag are the different types of stitches for embroidery picture, but similar in its properties such as width, filling, density, angle of the stitches etc. All considered classification denote such type of stitch as "satin", except "Epsima, NPP" (Fig. 4), wherein the satin is determined a "glad'" instead. M. Belova [1] believes that "satin" and "glad'" are different names of the same type. D. Chernenko [3] (Fig. 2) considers "satin" and "glad'" different types of embroidery stitches. If we carefully analyze the picture of binding (Fig. 2c), it is similar to the type of "zigzag" (Fig. 8b).



Fig. 8. Basic embroidery stitches that fill the form of the object: a - satin; b - zigzag; c - tatami

The same picture is the type of stitch called "satin" (Fig. 5c) in classification by M. Belova. Yet it should be noted that in the research [3] "glad'" was selected as on of the three types proposed by the author for the experimental filling from (Fig. 9).



Fig. 9. Glad' by the classification of D. Chernenko [3]

If we compare Fig. 2c and Fig. 9, they are completely different patterns. "Glad'" in Figure 9 is similar to "tatami" (Fig. 8c), not onlyby the picture, but also in their characteristics. So "glad'" in the classification by D. Chernenko stays uncertain.

The last type of traditional classification – a "fill", is completely filled with stitches, veiled form. This is quite successfully shown in [7]. In this classification, the category of "fill" contains satin, zigzag, tatami and others (Fig. 6) in their characteristics.

#### CONCLUSIONS

1. So as you can see, the presented classification types of embroidery stitches there are not even two identical ones.

2. The analyzed classifications are formed by the basis of specific embroidery software editors tools, but today there is no uniformity machine embroidery, uniform classification of embroidery stitches types. 3. The most complete, in our opinion, is the classification based on Wilcom ES editor.

4. This classification is based on the completed type of stitch fillings that deliver the basic artistic composition elements - contours, lines and marks.

5. With such approach, there may be considered geometrical and visual features of completed stitch fillings.

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#### АНАЛИЗ КЛАССИФИКАЦИИ ТИПОВ СТЕЖКОВ МАШИННОЙ ВЫШИВКИ

#### Галина Репка, Анатолий Мычко, Инесса Дейнека

Аннотация. В статье рассмотрены вопросы проблем отсутствия единой терминологии машинной компьютерной вышивки несмотря на возросший интерес к этой отрасли швейной промышленности, а также существующие классификации типов вышивальных стежков, которые основываются на базе конкретных программных инструментов редакторов машинной вышивки. В ходе исследования было установлено, что одним из наиболее универсальных редакторов машинной вышивки на сегодняшний день по праву является Wilcom ES. Установлены основные типы машинной компьютерной вышивки.

Ключевые слова: машинная компьютерная вышивка, типы стежков, классификация.

# Application of artificial intelligence methods to the study and analysis of the causes of employee turnover at enterprises

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S u m m a r y. This article deals with the importance of the staff turnover problem at the enterprise. The author proposes to study this problem using clustering method by the means Deductor analysis platform. The study determines the cause and the dominant factors of employee turnover, employee groups are distinguished by professional, age, gender and other criteria, the impact of specific reasons on resignation of these groups of employees is considered. The results of these studies enable the managerial staff of a company to make the most appropriate adjustments to the personnel policy in order to reduce employee turnover.

Key words: personnel, staff turnover, clustering, cluster (segment), Kohonen maps, personnel policy, the causes of employee turnover, factors associated with staff turnover.

#### **INTRODUCTION**

The market is constantly changing. Enterprises have to be dynamic and able to adjust not only to the external changes, but also to their speed. In this case, an organization should be not a frozen system but a mobile agency with one constant factor - the updating and continuous development [3]. Modern type enterprise should focus on process and personnel management. Human Resource Management is a leader in enterprise management system [10].

Staff is a major resource in many companies [17]. Today, most of the leaders are aware of the importance of personnel policy issues. Appropriately selected labor collective, the team of associates is able to deal with the serious challenges the company faces. Therefore. implementation of all HR functions, such as organization, motivation, planning and control is very important and upto-date.

Today the instability of economy is directly manifested in the growth of the staff yield stress rate at the enterprises of all types and forms of ownership [6]. It can lead to the loss of profit, resignation of skilled workers, product quality deterioration, increase of flawed products quantity and growing absenteeism. In order to control resignation and understand how to keep the best employees, it is necessary to determine the reasons why people leave the company. Collection and analysis of emplovee information is extremely important for studying the reasons of resignation. The problem of staff turnover as a part of its work is quite acute now and has great practical value to companies that are developing actively [7]. Since the staff is in constant motion due to

hiring and firing of workers, much less specific applied research and methodology is aimed at managing staff turnover in the company [14].

In the history of management human evolution is viewed as a basic element of production and management activities, it is reflected in classical economic theory in the works of E. Mayo, A. Maslow, D. McGregor, F.Taylor, A. Faiola.

However, despite practical demand, science has not developed a holistic concept and technology of HR. In this regard finding ways to assess and techniques to reduce yield stress of staff remains an unsolved question personnel management research. The novelty of this study lies in the use of artificial intelligence methods to solve the problems of personnel management [11].

## RESEARCH ANALYSIS AND THE PURPOSE OF THE RESEARCH

The problem of personnel management is considered in the works of such foreign and Ukrainian scientists as G.V. Shchekina, L.K. Averchenko, R. Daft, A.P. Egorshina, N.N. Kabushkin, A.J. Kibanova, D. Krasowski, M.N. Magura, V. Svistunova, L. Nikiforova, Y. Pustynnikova.

managers Foreign identified the following factors associated with staff turnover: age and length of service, job satisfaction, and work activity. Special studies examining the dominant factors of job quitting were conducted in the USA. Studies have shown that the determining factor is dissatisfaction with the nature of work, working conditions and management, so to prevent turnover it is necessary to take it into account. The interdependence of staff turnover rates and overall job satisfaction level is confirmed by other studies. For example, West German sociologists studied the relationship between the amount of resignations and such indicator as the overall incidence of staff. In this case, the two parameters were compared with the size of the companies surveyed. As a result, there were two major findings common for all industries: as the company increases in size, turnover reduces and the incidence of staff increases. Based on these findings, the authors put forward a thesis that dissatisfaction with work at small enterprises is manifested mainly in the form of staff turnover, and in larger ones - mainly in the form of skipping work, using the poor health excuse.

satisfaction To increase labor of employees companies in industrialized countries use a variety of programs, including those aimed at improving in-house staff mobility. For example, a program "Find work on the phone" was developed in "Hanover" (New York). It is designed to keep staff up to date about the movement opportunities within the firm. In the personnel department a mobile sector is created, it finds the employees whose skills and qualifications are not fully disclosed and involved at their positions, identifies the candidates for higher positions.

Western managers assign an important role in reducing employee turnover to newcomers' adaptation, in which information materials for new company workers take major part.

According to Western experts, in Japan, compared to the West, there are more opportunities to meet the needs of workers at an enterprise. The need of security in Japan is satisfied to a greater extent than in the West, due to the current practice of lifetime employment. A Japanese company and its traditionally formed relationships between people provide a suitable environment for satisfying social needs. This is facilitated with a widespread practice of informal meetings between the employees representing one and the same or different levels of hierarchy after the working day is over, during which various work issues are discussed and often important decisions are made. A Japanese company to a greater extent than Western one meets people's need to be respected, because it applies the principle of promotion in the business hierarchy depending on the length of service [2].

However, despite the practical importance, science has not yet developed a coherent concept and technology of managing this process. In this regard, finding ways of assessment and methods of the staff turnover reduction is still important.

The object of the research is manufacturing processes industrial on enterprise. The subject is the impact of manufacturing processes on the environment. The main purpose of the research is the implementation of environmentally oriented enterprise management to minimize the negative influence of its activities on the environment and development of approaches to the regulation of water use in the industrial production.

The aim of this work is to study the processes of personnel management, human resources policy of the company.

The object of analysis is a private company, regional center of implementation "Ahrotsentrnauka."

The subject of the study is the business processes associated with managing staff.

## **RESULTS OF RESEARCH**

As a system, human resource management can achieve socio-economic goals - meet the needs of both workers and the manufacturing process, through implementation of various HR functions.

The purpose of the HR process is to meet the needs of the production process in the required quantity of human resources, in quality and timing set, life satisfaction, social and psychological needs of employees. In this sense, the goals of personnel management can be viewed in socio- economic terms.

Mechanism of implementing HR processes lies in personnel management strategy, for certain HR purposes it is implemented more specifically through personnel policy.

Optimization and stabilization of staffing employees' internal facilitates rotations, providing job displacement employees with a workplace within the company and external that is firing employees who do not meet the requirements with their qualities and professional competence, that applies to an employee in a particular job. Evaluation of professional level and quality of functional responsibilities of company staff in "Ahrotsentrnauka" conducted was in accordance with procedures developed and periodic approved by appraisals [15]. Conclusion on whether the knowledge, skills, experience, business and personal characteristics of candidates for positions match corporate culture was brought to the attention of company management and is crucial when applying for a job at the company.

Creating an effective system of employee motivation means providing a direct and stable interest of every employee in achieving planned performance of personal and group work, aiming at the point where actual results exceed the planned ones. Basic component of motivation and stimulation of the company's financial remuneration employees is а mechanism which provides interconnection between payment and results. The basic principle of remuneration is equal pay for equal work, which means that employees occupying the same complexity and value positions (jobs) and showing the same performance should have the same level of salary [6].

Financial remuneration of staff consists of a constant part, i.e. guaranteed wage which serves as a base salary, and a variable part which is a function of the employee's, department's the whole company's or productivity. The base salary amount depends on the category of office and official rate established according to the employee's evaluation for the year. The variable part of remuneration is paid as a bonus. For the management of the company the amount of reward is calculated based on the entire company's financial performance. Department heads and staff support services remuneration is calculated as a reward for the high level of professionalism (no more than 100% of the salary). For managers and employees of major divisions reward is paid for monthly economic results of the unit (ranging from 1 to 5 % of the profits earned during the month).

One of the important tasks of the personnel policy of a company is to create and support institutional order, strengthening of

diligence, responsibility of employees for performed duties. The most important condition for achieving the strategic goals of the company is the unconditional fulfillment of duties by all employees, strict observance of labor and production discipline, managers being demanding to subordinates, unconditional fulfillment of orders, instructions and work tasks by subordinates.

Forming and strengthening the corporate culture should be carried out through enterprise-wide activities aimed at instilling in employees a sense of community, a sense of belonging to the company, loyalty and reliability. Creating a positive image both within the enterprise and beyond it promotes cultivation and promotion of corporatism and positive socio-psychological atmosphere at the workplace.

HR policies can be assessed using performance indicators of staff.

Personnel disposal coefficient  $K_{vk}$  is determined by the ratio of the number of employees dismissed for all reasons during this period to the average number of workers in the same period:

$$K_{vk} = \frac{P_{uv}}{P_s} \cdot 100\%$$

In 2013, 3 people were dismissed in the company "Ahrotsentrnauka", while only 45 people are listed. Disposal coefficient is 0.0667 or 6.7 %.

Staff reception coefficient  $K_{pk}$  is determined as the ratio between the number of workers hired during the period and the average number of workers during the same period:

$$K_{pk} = \frac{P_{pk}}{P} \cdot 100\% \,.$$

In 2013, 3 people were hired. Staff reception rate is 0.0667 or 6.67%.

Personnel stability coefficient  $K_{sk}$  should be used when assessing the level of production management at the enterprise as a whole and in individual sections:

$$K_{sk} = 1 - \frac{P_{uv}}{P + P_n} \cdot 100\%$$
,

where:  $P_{uv}$  is the number of workers laid off from the company of their own accord and in violation of labor discipline during the reporting period,

P – is an average number of employees at the enterprise during the previous reporting period,

 $P_n$  – the number of newly admitted employees during the current reporting period.

The company's personnel stability coefficient is 0.938 or 93.8 %. The level of staff turnover *TK* is estimated as the ratio between the number of employees who quitted the company due to the reasons connected with yield strength ( in our case, due to violation of labor discipline), and for reasons not connected with operational requirements  $P_{tk}$ , and the average number of employees  $P_{cc}$ :

$$TK = \frac{P_{tk}}{P_{cc}} \cdot 100\% .$$

To reduce staff turnover, it is necessary to collect complete and timely information about the reasons of employee's leaving an enterprise. A questionnaire is used to identify the motives of resignation.

Prevention of actual employees' layoffs should be based not only on the analysis of their resignation motives, but also on information about potential fluidity of motivation - readiness of employees to change jobs. This approach is consistent with the principles of advanced management. Knowing the factors of employee's readiness to quit his position can help determine what caused his dissatisfaction with the workplace and how to reduce the degree of dissatisfaction, thereby preventing dismissal.

Thus, the basis of HR is to elucidate the process of staff turnover. Knowing these

patterns makes it possible to determine the most effective managerial impact.

Using the above equation, staff reception rate was calculated. It equaled 6.67 %. Thus, the stability coefficient shows a stable level of organization as well as the stability of frames does not exceed 90-95 %. Disadvantages of personnel management at the enterprise lies in imperfect system of employee retention. The need for staff is not generated. This can cause unnecessary position being created for which the selection is held, while some other employees are fired. The company bears material losses, loss of professionals and loss of image. The company has no staff adaptation program either. As a result, new employees feel as "aliens" in the company. Their functions are often not clearly explained to them on probation, they are not introduced into the office. Therefore, according to experts, their productivity is about 40 %, in contrast to 60-70 % by those who are engaged in adaptation programs. Statistically, a higher percentage of resignations from work occurs between 2 and 5 months of work - this is due to the lack of staff adaptation programs.

At the considered enterprise the staff turnover rate does not significantly exceed normal rate. However, the analysis of company's personnel showed that all employees who have left the company did it voluntarily. It is therefore necessary to determine the cause and the dominant factors of staff turnover, select a group of professional workers, age, gender and other criteria, and to study the impact of specific reasons on dismissal of the employees of these groups.

This paper suggests using artificial intelligence methods, namely clustering and classification methods [4]. Data mining computer technology and OLAP enable to implement them in real time [17].

Clustering (or cluster analysis) is a process of partitioning a set of objects into groups called clusters [1]. Each group should be comprised of "similar" objects, and the objects of different groups should differ as much as possible. In order to perform clustering, Kohonen maps and a "Clustering" tool of an analytics platform "Deductor" were used [5].

A Kohonen self-organizing map is a competitive neural network with unsupervised learning, which performs the tasks of visualization and clustering, it is one of the versions of the Kohonen neural network. It is used in solving the problems of modeling, prediction, etc. A Kohonen map projects multidimensional data in a lower dimensional space (usually two-dimensional) and is usually used for data visualization, so that one can "see" the presence or absence of cluster structure in data, the number of clusters, the laws of the joint distribution of attributes, relationships between variables. Kohonen maps are neural networks, in which the training process of neurons takes into account the topology of the network and uses the function that defines the influence of a neuron on its neighbors.

Kohonen maps alone do not solve the task of cluster analysis and identification of dependencies. They only allow us to make hypothesis about the cluster structure and the number of clusters, the relationships between the values of individual variables. It is sometimes impossible to distinguish certain actually present and statistically proved dependencies using only Kohonen maps [5]. This is why this study carries out clustering also using the "Clustering" tool of the analytical platform "Deductor" [8].

Clustering with k-means and g-means algorithm families is used for the same problems as Kohonen maps, but in this case the results cannot be visualized in the form of a two-dimensional colored map.

The k-means algorithm is based on the principle of in a certain sense optimal partition of data in k clusters. The algorithm attempts to group the data in clusters so that certain function of algorithm reaches its extreme.

The analysis algorithm can be represented with the following steps:

1. Object samples selection for analysis.

 Defining a set of variables, which will be evaluated by the objects in the sample. If necessary normalization of variables is done.
 Data modeling. 4. Application of cluster analysis to creating groups of similar objects (clusters).

5. Presentation of the analysis results.

As a result of data cluster analysis, groups of resigned employees with various resignation reasons were identified. The data used in the analysis was obtained from a private enterprise – regional integration center "Agrocentrnauka" and all its regional offices. The input data was comprised of dismissal orders and decrees, employment records of employees, timecard data, the set of documents that one should present upon the accceptance for employment.

The leaving workers were surveyed, since it's well known that the official information (the reasons for resignation specified in the dismissal order and the employment record) does not always correspond to the real state of affairs. Interviewing (surveying) the leaving employees allows to understand the real reasons behind resignation and to identify adverse trends in community life in time to take corrective actions [4].

Questioning resigned employees demonstrated that the main factors in the decision to quit are:

1. Inadequacy of social and psychological climate and social security, interpersonal difficulties, conflicts.

2. Lack of career development, opportunities for self-realization of an employee.

3. Violation of labor regulations.

4. Inadequacy of material incentives, ofn the actual reward for individual achievement in the overall result.

After constructing a Kohonen map, four types (segments) of resigned employees were identified. The number of segments was specified to the number of reasons for dismissal (Fig. 1).



Fig. 1. Segmentation of resigned employees

Cluster number 0. Currently cluster got 26.3 % of the employees who left . These are men and 28 years, with wages up to 2700 UAH. 58.4 % of employees in this cluster have experience of 3 years, 69.7 % have as an engineer. Reason for leaving 57.3 % of employees are lower wages, 32.6 % of employees in this cluster freed due to lack of opportunities.

Cluster number 1. During this cluster gets the least number of employees (4.7 %). Not married men over the age of 28 years (28-33 years - 31.3 %, from 33 years 62.5 %), experience of more than 4 years post appraiser (68.8 %). Most employees in this cluster resigned due to lack of prospects (62.5 %).

Cluster number 2 – the largest by number of employees that it includes (28.9 %). That married men over the age of 28 years, with a long experience (over 4 years) and wages (over 3400 UAH.) . Employees in this cluster have different reasons for leaving:

44.9 % - lack of prospects,

20.4% – a violation of labor regulations, 15.3 % – adverse psychological climate in the team,

13.3 % – low wages,

6.1 % – retirement.

Directors and department heads resigned due to retirement and because of the lack of prospects.

Cluster number 3 - a young woman to 28 years, with experience of 3 years and wages to 2400 UAH. Most are employees of the personnel department . 75 % of employees in this cluster resigned because of low wages.

Cluster number 4. This cluster is represented by unmarried women Accounting and Human Resources Manager at the age of 28 years, with experience of more than 4 years and salary 2400-3400 UAH. 50 % of employees in this cluster retired unfavorable psychological climate in the team, 38.9 % – in the absence of prospects.

Cluster number 5 – the married women of the personnel department over 28 years. 70.3 % of women in this cluster have an economist with salary 2400-2700 UAH. The reason for their dismissal became unfavorable psychological climate in the team 13.5 % from staff salaries to 2400 UAH. Who left the company due to retirement.

Cluster number 6 – a married women accounting, 64.7 % of whom have worked for over 7 years . Salary 2700-3400 UAH, 55.9 % retired because of adverse psychological climate in the team, 20.6 % – in the absence of prospects.

Cluster number 7 - single young menunder 28 who have as an engineer (60.9%) and appraiser (39.1%). Men of this cluster have salary 2700-3400 UAH. released, mainly due to violation of labor regulations, due to adverse psychological climate in the team retired employees with wages over 3400 UAH.

The disadvantage of using Kohonen maps is that by themselves, these neural network task cluster analysis and identification of dependencies do not resolve. They only allow the hypothesis of the presence of cluster structure and the number of clusters dependencies between the values of certain variables. Hypothesis should be checked and confirmed by other means. For this purpose, conducted clustering method k-means, which confirmed the results. From the above analysis we can draw conclusions about the reasons for each dismissal.

The study produced the following results:

- The main reason for resignation in the given company is the lack of prospects, 32.2 % of employees leave for this reason (Fig. 2).
- The smallest number of resignations was made due to the violation of labor regulations (15.5%) (Fig. 2).
- Adverse social climate in the team was specified as the reason for resignation by most women aged 28-33 with working experience of 5 years, most of which are employees of HR and accounting, as well as single men with experience of 2-3 years and wages of about 2000-2500 UAH.
- Heads of departments and women working in accounting with extensive experience in the given company resigned because of the lack .



Fig.2. Clustering of resigned employees. Factor - "Cause dismissal"

- Violations of labor regulations is the reason to quit for mid-level specialists.
- Men and women aged 25-26 with little experience and wages of about 2000 UAH. and employees aged 32-35 with the experience of about 5 years, most of which are married and have children, were not satisfied with their wages.

Recommendations to reduce staff turnover.

In order to increase the material interest of employees, enter promotional allowances, with the volume of work performed, bonuses for length of service in the enterprise.

To eliminate violations of labor regulations, regimes of work and rest in the company administration to devise an action plan to protect the interests of employee strictly monitor compliance with the rights of employees are required by law [11].

To eliminate unsatisfactory sociopsychological climate and social security, interpersonal difficulties and conflicts must form a team of formal and informal rules , norms of behavior , attitudes and values, and thereby achieve a high level of corporate culture.

To create the conditions for self and career development of employees is necessary to introduce a system of job evaluation and personnel reserve.

One solution of the problem of forecasting the reasons for employee dismissal

and the duration of his work is the use of algorithms that solve the problem of classification.

Classification problem is similar to the task of clustering is its logical extension, but it differs in that class of investigational data set previously conditioned. To solve the problem of resigned employees classification depending on the reasons for their dismissal and seniority in the company, the method of decision trees is applied. In the simplest form a decision tree is a way to represent rules in a hierarchical, consistent structure [18].

The advantages of decision tree is fast formation, generation of rules in an easy-tounderstand form in areas where expert knowledge is difficult to formalize, the classification model is intuitive, high prediction accuracy compared to other methods (statistics, neural networks), the construction of nonparametric models.

However, decision trees have several drawbacks: repetition of some parts in the construction of decision tree, in some cases, creating the rules of interpretation of a complex, applicable to data sets with a large number of possible outcomes.

Nowadays there are many algorithms implementing decision trees: CART, C4.5, CHAID, CN2, NewId, ITrule and others. But the most widely spread and well-known ones are CART and C4.5.

CART (Classification and Regression Tree) is an algorithm of binary decision trees

construction, a dichotomous classification model. Each node in the tree partition has only two offspring. As the name implies, the algorithm solves the problem of classification and regression.

C4.5 is an algorithm for constructing decision trees, where the number of descendants of the node is unlimited. This algorithm doesn't know how to work with continuous target field, thus it only solves classification tasks [20].

Current research paper used C4.5 algorithms to construct the decision tree. Working with the algorithm requires compliance with the following rules: each entry of a data set must be associated with one of the specified classes, an attribute of the data set should be a labeled class, classes must be discrete (each example should belong to one of the classes), the number of classes should be much less than the number of records in the test dataset.

The drawback of the C4.5 algorithm is that it runs slowly in large data sets. To determine the reasons for dismissal and the likely duration of work in the company two decision trees are built. The first decision tree is built to determine the value of a categorical dependent variable "Reason for leaving".

In order to classify the data by means of mathematical methods it is necessary to have a formal description of the object. This description is a database of employees who resigned.

The source data is divided into two sets: training and test. Training set is a set that includes the data used for training (design) model. This set contains input and output (target) value examples. Original values are assigned to verify the model. The test set also contains the input and output values of examples. Here, the initial values are used to verify the model. The division into training and test sets is carried out by dividing the sample in a certain proportion. Training set is 95 % of the original data sets, while test set is only 5 %.

The challenge is to transmit such database attributes as "Sex", "Age", "Marital status", "Department", "Education", "Position", "Seniority in the company", "Wages", "Number of children" to determine what caused an employee to quit.

The normalization of the fields in the decision tree is required. The range of numeric values in the fields "Age", "Seniority in the company" and "Wages" is divided into 4 intervals. The internal nodes of the tree (gender, age, marital status, department, position, seniority, wages) are attributes of the above database. These attributes are called forward or splitting attributes. Finite tree nodes or leaves are class labels, which are the values of the dependent categorical variable "Reason for leaving".

Each branch of the tree which comes from the internal node is marked as splitting predicate. The latter can relate only to one attribute splitting this node. A characteristic feature of splitting predicate: each record uses a unique path from the root tree node only to one solution. The criterion is combined information of attributes and predicates splitting node.

The most important attribute is "Salary", "Position" and "Age". These attributes make the largest contribution to classification of the source field "Reason for leaving". The degree of dependence of the output fields on "education", "number of children" and "family status" is insignificant.

## CONCLUSIONS

1. To improve the personnel maintenance policy the current research paper examines the main areas of personnel policy based on interrelated management functions at strategic, tactical and operational levels.

2. Implementation of effective personnel policies in the current environment requires effective use of human resources in planning, organization, motivation and control of personnel. This becomes possible by means of modeling. A set of models described in the master's work allows fully reflect the managerial staff based on the main functions of management.

3. Any mathematical model which describes a particular object, phenomenon or

process requires a certain numerical parameters that characterize them. Since the purpose of modeling is to search the best values, then planning, organization, motivation and control of personnel is implemented in the enterprise system based on modeling the management process which will allow and provide further improvement of managerial staff efficiency.

4. The intelligent analysis of staff turnover was developed to study the problem of staff turnover in the company and to find the ways of reducing it. The system is designed for strategic and tactical planning of personnel policy and includes a database of employees, a description of the required data structures, staff turnover analysis methodology using artificial intelligence methods and software.

5. Intelligence system is used in analysis of staff turnover at a company with minimum time and financial investment to determine the cause and the dominant factors of staff turnover, to select a group of professional workers by age, gender and other criteria, and to study the impact of specific reasons on dismissal of employees of these groups. This will allow the managerial staff of a company to make the most appropriate adjustments in personnel policy for each of the selected employee groups to reduce staff turnover.

6. This system of data analysis provides information necessary for decision-making in hiring, the results can be taken into account in the design of incentive mechanisms to stimulate and increase the interest and satisfaction with work in order to improve the system of remuneration.

7. It should be noted that the results obtained using the proposed model are not completely accurate because it does not take into account the individual characteristics of each employee. However, the results obtained by this method can be used as an additional method of decision-making.

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#### ПРИМЕНЕНИЕ МЕТОДОВ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА ДЛЯ ИССЛЕДОВАНИЯ И АНАЛИЗА ПРИЧИН ТЕКУЧЕСТИ КАДРОВ НА ПРЕДПРИЯТИЯХ

#### Наталия Рязанцева

Аннотация. В данной статье рассматривается актуальность проблемы текучести кадров на предприятии. Автор статьи предлагает исследовать данную проблему методом кластеризации с помощью аналитической платформы Deductor. В ходе исследования определяются причины и доминирующие факторы текучести кадров, выделяются группы работников по профессиональным, возрастным, половым и др. критериям, рассматривается влияние определенных причин на увольнение работников этих групп. Результаты проведенных исследований позволяют наиболее руководству предприятия внести целесообразные коррективы в кадровую политику с целью уменьшения текучести кадров.

Ключевые слова: персонал, текучесть кадров, кластеризация, кластер (сегмент), карта Кохонена, кадровая политика, причины текучести кадров, факторы, связанные с текучестью кадров.

## Study of waste dumps impact on the adjacent areas

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S u m m a r y. The paper presents the results of field studies of the agricultural soil contamination resulting in washout where the soil are contiguous to the waste dump. To study the contamination of the soil contiguous to the waste dump site, plant samples were taken. Based on the findings, statistical data processing and checking for uniformity and authenticity were carried out.

Soil and vegetation analyses for heavy metals content were carried out.

Key worlds: waste dump, soil, toxic elements, heavy metals

## INTRODUCTION

Coal mining in Donbass has been carried out for over 200 years.

Coal enterprises stand with the largest industrial polluters in importance. Therewith, colossal environmental damage is inflicted not only directly in the process of coal mining, but also many years after its termination [8].

One of the most important technical processes that accompanies coal mining and processing at the coal-preparation plants is the transportation and storage of the waste rock that comes from coal mines heaps and coal-preparation plants. Currently Ukraine's coal industry has about 1130 waste dumps. On the balance sheet of coal mining and coal preparation companies of Lugansk region, there are about 537 waste dumps, covering the area of more than 3100 hectares [12].

It is set that the size of the territory, exposed to harmful-influence of waste banks, 10-15 times exceed the area of dumps. Under every dump from 2 to 10 ha of fertile and suitable for industrial and housing development earth is occupied. The sizes by the affected of dumps zones hesitate within the limits of a 500-1000 m. Accordingly, more than 11 thousand hectares of soils are not suitable for the economic use.

Stockpiling of the dumped rock that operates the coal companies, has a range of significant drawbacks. One of the most significant is the unintelligent use of the space under the dumps, which leads to the reduction of agricultural land and, as a result of wind and water erosion, to contamination of the abuttal.

Large harm is done by the development to erosion on the slopes of dumps, because overwhelming majority of them presented by waste banks with pouring out of breed in form of a cone.

The washed off breed is very toxic, because oxidization of brazil stimulates the poured out neutral breed becoming sulfur-acid in course of time. Sulphuric acid derived as a result of oxidization of brazil dissolves different metals, and they migrate on adherent territories. In course of time soil adherent to the waste banks becomes not suitable for the development of agriculture from solutions, getting to soil from dumps, that have high concentrations of sulphuric acid, sulfates and movable forms of heavy metals quite often.

The scientists found out that from 1 hectare of a waste dump surface are windblown up to 10 tons of dust and more than 35 tons of silt, a significant amount of water-soluble salts, radionuclides and heavy metals are water flown. Consequently, the erosion processes lead to transportation of heavy metals in a mobile form into the soil [14, 16]. At a distance of 0.5 km along the perimeter of the waste dumps, chernozem completely loses its properties to a depth of 0,6 m, in the area of 5 km can be observed such phenomena as accumulation of heavy metals, loss of humus and soil degradation [9].

Considerable damage to the natural environment brings spontaneous combustion of the waste dumps. The main cause of spontaneous combustion is coal oxidation accompanied by release of a large amount of heat which accumulates in the interstices of soil and provides the ignition of combustible materials. In some dumps, these processes are so intense that the debris is heated to high temperatures and burn, releasing substantial amounts of hydrocarbons, soot, nitrogen oxides, sulfur, carbon, etc. Even those waste banks that seem extinct actually continue to smoulder. Waste banks keep high inner temperature, besides arsenic, mercury, cvanides. sulphur and other harmful substances and their compounds are accumulated surplus. On the average, from one smouldering dump an amount of 10 ton of oxide of carbon, 1,5 tones of sulphureous anhydride and far of admixtures of other gases.

Due to the fact, arrangement of protection zones around the waste dumps becomes necessary, which leads to the extension of safety exclusion area [5]. Up to 86% of the waste dumps are exposed, 10% - partially overgrown and only 4% have a developed vegetation cover [11].

## MATERIALS AND METHODS

Environmentally safe existence of all natural components of the soil is one of the

main tasks of our time. Various aspects of the ecological safety problem is the object of attention of many researchers, among them are: Abrosimov E.I , Averin G.V., Alekhin Y.I, Baklanov V.I., Gavrilenko Y.M , Driban V.O., Ermakov V.M., Zborschik M.P., Zubova L.G., Zubov A.R., Kolesnik V.Y, Krasavin A.P., Krenida Y.F., Maksimovich M.G., Motorina L.V., OsokinP.P., Panov B.S., Pop Y.M., Prosvirnye Y.A., Rud'ko G.I. and others [3, 6]. The work of scientists is dedicated to different aspects of protection from water and wind erosion on the surface of the waste dumps by mine technical and biological recultivation. These measures can reduce the solid runoff, but have almost no effect on the heavy metals ion sink, sulfate ions and hydrogen ions sink.

The purpose was to study the effect of a coal mine waste dump on the contiguous agricultural crops area. To reach this goal the following problems were set and solved:

- examine the condition of the waste dump No. 3, Lisichansk,

- identify growth index of the crops growing in the contiguous areas using the quantitative estimation method,

- study the geochemical characteristics of the contiguous soil (to determine soil acidity and sulfate ions content),

- Perform the spectral analysis of soil and plant samples for the presence of heavy metals mobile forms.

## **RESULTS, DISCUSSION**

The research work was carried out on the waste dumps No. 3 Matrosskaya Mine, Lisichanskugol OJSC, which in 2010 was transformed from a conical (Fig. 1) into a flat one by flushing and lowering its top (Fig. 2), as well as its contiguous areas (the agricultural fields of the state owned farm Lisichanskiy).

Up to 2009, the waste dump No. 3 has been burning. In 2010, the waste heap was merged with the waste dump No. 4, terraced (Fig. 3), though, it wasn't planted. Consequently, the surface of the above waste dump is constantly exposed to water and wind erosion, the rocks break and fall to the foot and adjacent areas [4].



Fig. 1. Dump and adherent to him sowing to reforming



Fig. 2. Reformed waste dump and adherent to him sowing

On a figure 4 the investigated dump (kind from above) is presented.



Fig. 3. Incorporated and terraced waste dump



Fig. 4. Investigated dump (kind from above)

Observations showed that while melting of snow or thundershowers the streams of water from the surface of dump movelget on the field and move along it, bringing products the erosions deposited on the field as loops breadthways up to 50 m (Fig. 5).



Fig. 5. The rock, washed out to the adjacent areas

For studying the dynamics pollution of soils contamination neighborhood territory works were performed in two stages. At the first stage sampling of winter wheat was carried out in July, 2006. At the second stage (July, 2012) were selected sunflower vegetable samples. Tests were selected selectively, at distance of 50, 100 and 150 m from the bottom of a dump and at the same distance out of its zones (control).

During the vegetation development the samples were measured by the following indicators:

- number of plants per 1 m<sup>2</sup>, units,
- plant height, cm,
- an amount of grains, units,
- weight of 1000 grains, g.

For further analysis and evaluation of the data received, the data were checked for uniformity and the statistical ratios were calculated [6]. To check the data uniformity the Student's t- test analysis method was chosen [12].

According to the data received, tables and diagrams were compiled. The diagrams quantitatively illustrate how the washed-out rock influences and changes the establishment and the growth index of crops as exemplified by the sunflowers and winter wheat in the zone of influence of the waste dump (i.e. gray) and control points (i.e. light-gray), (Fig. 6-13).



Fig. 6. Number of plants per 1 m<sup>2</sup>, units (sunflower)

The change of indexes number of plants per  $1m^2$  of winter wheat and sunflower is traced. The number of plants hesitates from 4 to 9 units (sunflower) and from 56 to 88 units (winter wheat).



**Fig. 7.** Number of plants per  $1 \text{ m}^2$ , units (winter wheat)



Fig. 8. Plants height, sm (sunflower)



Fig. 9. Plants height, sm (winter wheat)

Proceeding from the presented charts, the change of indexes of height the winter wheat and sunflower is traced. The height of plants hesitates from 313 to 1041 sm (sunflower) and from 49 to 66 sm (winter wheat).

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Fig. 10. An amount of grains, units (sunflower)



Fig. 11. An amount of grains is in an ear, units (winter wheat)

Indexes of amount of grains in an ear hesitate in limits from 8 to 14 pieces (winter wheat) and from 95 to 176 pieces (sunflower).



Fig. 12. Weight of 1000 grains, g (sunflower)



Fig. 13. Weight of 1000 grains, g (winter wheat)

Proceeding from the presented charts mass of 1000 grains are varied from 18 to 56 g (sunflower) and from 36 to 57g (winter wheat).

The charts show that the indicators within the area of the rocks wash-out are significantly lower than the ones outside the waste dump influence zone, which indicates the negative impact of the waste dump on the establishment and growth rate of crops. Based on the foregoing, it can be concluded that vegetation within 150 m is exposed to contamination, and the growth of crops reduces significantly.

In the course of study the spectral analysis of the soil and sunflower seeds was carried out, as well as the chemical analysis of the soil. To determine the pH, the potentiometric method was used, to determine the sulfate ions rate - the quantitative method [14]. Trace element content in the soil and plant samples was determined by approximatequantitative emission spectral analysis method (Table 1).

Based on data from Table 1, pH changes and different sulfate ion content can be observed in comparison with the zonal steppe soil.

Acidity ranges from 6.0 to 8 (i.e., from acid to alkaline).

Sulphate content ranges from 0,004 to 0,31, indicating a significant increase of these ions in comparison with their natural level in steppe soil.

	Complian Is action	Rates		
	Sampling location	pН	$SO_4^{2-}$	
1	50 m	6,0	0,012	
	from the waste dump foot			
2	50 m from the waste dump foot	7,4	0,019	
	(verification)			
3	100 m	7,8	0,004	
	from the waste dump foot			
4	100 m from the waste dump foot	7,9	0,031	
	(verification)			
5	150 m	8,0	0,013	
	from the waste dump foot			
6	150 m from the waste dump foot	8,0	0,007	
	(verification)			

**Table 1.** Soil test results (soil acidity and sulfate ions content)

Thus, the data obtained shows that the adjacent area is characterized by a high content of sulphate ions. According to our data the territory that is adjoint to the dump is characterized by more intensive content of sulfate-ions. There are, also, changes as comparison with natural terms in content of hydrions, i.e. from weak-acid to the neutral reaction. It can be explained by the strongest washing off of dump breed as a result of water erosion on adjoint territory. There are also changes in the content of hydrogen ions in comparison with the natural conditions, i.e. from the weak acid to neutral reaction. These effects can be explained by a strong debris washout in consequence of water erosion to the adjacent area.

At the junction of sulfuric acid migration flows with natural soil, represented by common chernozem with neutral or faintly alkaline reaction of the environment, alkaline barriers are formed. As a result of pH increasing a number of elements are deposited on the alkaline barrier forming a geochemical anomaly (Fig. 14).





- 1 acid solution,
- 2 chernozem,
- 3 alkaline barrier  $(D_1)$

It is known that barriers for alkali (as in this case, which protrude prairie soil) deposited : Mg, Ca , Sr, Ba , Ra, Mn, Fe, Co, Ni, Cu , Zn, Pb, Cd, Hg, Be, Al , Ga, Y, Tr, Cr, P, As, U [1, 17, 18, 19]. The deposition of the heavy metals lead to contamination of the adjacent areas (Table 2).

Table 2. The results of spectral analysis of the soil adjacent to the waste dump

	-	•		•		-					
			Content (thousandths %)								
Element	Clark %	50 m from t he waste dump	50 m from t he waste dump (v.)	100 m from the waste dump	100 m from the waste dump (v.)	150 m from t he waste dump	150 m from the waste dump (v.)				
Pb	2*10 <sup>-3</sup>	5	3	2	2	2	1,5				
Cu	0,01	3	3	2	3	3	3				
Mn	0,08	100	70	70	70	100	70				
Ni	0,018	7	5	5	5	5	3				
Cr	0,033	20	15	10	10	15	10				
Bi	N*10 <sup>-6</sup>	0,3	0,2	0,2	0,2	0,2	0,2				
Mo	N*10 <sup>-4</sup>	0,3	0,3	0,2	0,2	0,2	1,15				
Li	0,004	3	3	3	3	3	3				
Zn	0,004	15	15	10	10	20	15				
Co	0,01	1,5	1,5	1	1	1,5	1				

		Content (thousandths %)							
Element	Clark %	50 m from the waste dump	50 m from the waste dump (v.)	100 m from the waste dump	100 m from the waste dump (v.)	150 m from the waste dump	150 m from the waste dump (v.)		
1	2	3	4	5	6	7	8		
Pb	$2*10^{-3}$	0,1	0,1	0,1	0,15	0,2	-		
Cu	0,01	5	5	7	10	7	5		
Mn	0,08	15	30	50	30	5	50		
Ni	0,018	2	1	1	0,7	1	0,5		
Cr	0,033	0,5	0,2	0,1	0,5	-	-		
Bi	N*10 <sup>-6</sup>	0,5	0,5	0,3	0,3	0,3	0,5		
Ba	0,047	10	10	-	10	-	-		
Мо	N*10 <sup>-4</sup>	0,3	0,1	0,3	0,2	0,15	0,1		
Li	0,004	1	1	1	1	-	-		
Zn	0,004	7	5	10	20	30	5		

Table 3. The results of the spectral analysis of sunflower seeds (ash), adjacent to the waste dump

Penetration of heavy metals into a plant tissues in excess amount leads to the malfunction of its organs and structures, and the greater the excess of toxicants is, the stronger the violation will be. As a result, plant productivity reduces (Table 3).

As seen from the data received as part of the study, build-up of polluting heavy metals (Pb, Zn, Cr, Cu) in the mobile form can be observed increased in the soil and seeds.

Based on the foregoing, it can be concluded that the heavy metals found in the adjacent soil are involved in the biological cycle and, thus, may further be passed on through the foodchain to man, causing a variety of diseases [2].

#### CONCLUSIONS

1. The results of measurements near the waste dump show that the survival index and plants productivity decrease. The indicators in the zone of rock washout are lower than the ones outside the waste dump influence zone, this goes to prove a significant contamination of plants with the washout of rock from the waste dump.

2. On adjoint to the waste banks territories, polluted with heavy metals, biogeochemical barriers appear, id est, by virtue of biogenic migration, there is an accumulation in the plants of chemical elements in anomalous concentrations substantially different from MPK (maximum possible concentration).

3. Therefore, we can conclude that the waste dumps are objects, causing significant damage to the adjacent soil, since in the process of burning, oxidation, and weathering, the whole spectrum of components within the dispersion halo is localized in the topsoil, which at a later stage of hydrogenous migration considerably impairs the vegetation regime.

4. The research results reasonably likely allow to assert that the soil contamination in the studied area is associated with the waste dumps. Therefore, continuous watch in the waste heaps impact area is a great currently important research and practice.
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#### ИССЛЕДОВАНИЕ ВОЗДЕЙСТВИЯ ТЕРРИКОНОВ НА ПРИЛЕГАЮЩИЕ СЕЛЬСКОХОЗЯЙСТВЕННЫЕ ЗЕМЛИ

#### Елена Савельева

Аннотация. Изложены результаты полевых исследований загрязнения сельскохозяйственных почв, прилегающих к отвалу, в результате смыва изучения породы. Для загрязнения почв прилегающей к отвалу территории были отобраны растительные образцы. По результатам произведена статистическая обработка данных и проверка на достоверность. однородность и Определены кислотность и содержание сульфат-ионов в почве. Произведены анализы почвы и растительности на содержание в них тяжёлых металлов.

Ключевые слова: террикон, почвы, токсичные элементы, тяжёлые металлы.

# Method for identification the recording device of digital images

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S u m m a r y. The method to reveal isolated features in digital image connected with its recording device is proposed. The algorithm of signal decomposition on the basis of wavelet analysis is given, the identification criteria of isolated features in the image structure are singled out. The identification algorithm of a recording device of digital images on the basis of the usage of singled out isolated characteristic features has been developed. Experimental research to estimate the accuracy of identification of digital images recording device has been done.

K e y w o r d s : an image, spectral characteristics, wavelet decomposition, isolated features.

## **INTRODUCTION**

Research of and development instrumental means to control multi-media data, integrity authenticity both the data themselves and the device identification for media signal formation became very relevant due to their usage as a proved basis in forensic medical agencies and so on [16, 20]. It is necessary to note that at present multi - media data as evidence play a secondary role due to the lack of necessary means for the analyses of their authenticity. integrity and correspondence with the device forming the signal.

Identification of the formation media signal source is one of the most important and very solved- difficult tasks in the aspect of authenticity media- data estimation. There are several approaches to solve this problem. The problem of the source identification has been studied in works [9, 1, 2] for images groups having been received from several cameras under controlled conditions. In work [8] the authors have offered the method to identify separate imprints of image sensors on the basis of additive noise (PRNU). Earlier K. Kurosawa has offered a unique method of video-camera identification with the help of defective pixels in CCD sensors [14, 18, 19]. In work [21, 9] the identification of camera source has been researched for two different cameras using additional links (connections) during charge transition for CMOS sensors. The authors have shown that their method reveals the camera-source with high accuracy even for images taken in a wide light range. There are some well-known works [10, 11, 13, 15] which deal with the division of sources

forming the images into classes. However, it is necessary to mention that none of the described methods possess high enough revealing accuracy to be used as a proved base.

Thus, the aim of the work is the research and the development of authenticity method for the device forming digital images on the basis of the analysis of apparatus noise characteristic features.

## METHODS OF RESEARCH

Recorded digital data of a digital image is presented as a sequence of its amplitude readings which are the result of interaction of two components - the first one is a recorded scene and the second component is apparatus disturbances. If statistical characteristics of these two components were approximately equal it would be senselessly to set a task of dividing signal and disturbances. However, it is known that in a majority of important cases frequency responses of signals and disturbances are separated. Apparatus disturbance power is localized mainly in a high- frequency range in comparison with a signal [8].

From the point of view of modern conceptions digital images in any random section represent themselves a set of different self-similar formations both at the level of outcome scene and at the level of disturbances. It can be supposed that self-similar structures characterizing the scene will be changeable over a period of enough represented images sample received from the same formation image device [6]. At the same time, from physical thoughts it is evident that formations responsible for characteristic features of formation images devices must possess more stable characteristic features over a period of enough great images sample received from one formation images device.

The researches of graphical files show the availability of a great number of highfrequency bit structures of "special kind" the number of which in different fragments of the same file greatly differs from accidental one [7]. Here, stable regularities in the distribution of such structures by the same digital image are watched. This fact is the evidence of the existence of self-similar multi- fractional images in the elements of graphical files. These formations can be matched up the statistical features which are the results of hidden regularities in the device of a digital image formation [6].

Let's consider the algorithm of revealing features in the image structure on the basis of wavelet transformation.

Wavelet is a transformation which arranges the signals by extended and shifted wavelets  $\psi$ . As wavelet  $\psi$  has a zero mean value, so wavelet is an integral which:

$$Wf(a,b) = \int f(t) \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) dt, \quad (1)$$

measures the change f in the range of point b, the size of which is proportional to a. While the scale a is striving for zero the wavelet-coefficients characterize properties of function f in the vicinity of a point b. If function f by m times is differentiated by [v-l;v+l] and  $\rho_v(t)$  - is Tailor polynomial in the vicinity of v, then:

$$\rho_{\nu}(t) = \sum_{k=0}^{m-1} \frac{f^{(k)}(\nu)}{k!} (t-\nu)^{k} .$$
 (2)

The error of such an approximation  $\varepsilon_{v}(t) = f(t) - p_{v}(t)$  satisfies the condition:

$$\forall t \in [v-l; v+l].$$

$$\left|\varepsilon_{v}(t)\right| \leq \frac{|t-v|}{m!} \sup_{u \in [v-l;v+l]} \left|f^{m}(u)\right|.$$
(3)

The order of differentiability f in the vicinity of v determines upper bound of error  $\varepsilon_v(t)$  at t striving for v. Lipshits smoothness makes more precise this upper bound introducing non-integral index on the basis of the following definition.

In work [17,12] it is shown if wavelet  $\psi$  has *n* zero moments, that is:

$$\int_{-\infty}^{+\infty} l^k \psi(t) dt = 0, k = \overline{0; n-1}, \qquad (4)$$

and *n* derivatives, then for  $f \in L^2(R)$ , satisfying uniform Lipshits condition  $\alpha, \alpha \le n$  at [a,b], A > 0 exists, that:

$$\forall (s,u) \in \mathbb{R}^+ \times [a,b] | Wf(s,u) | \le A s^{\alpha + 1/2}.$$
 (5)

Inequality (5) is the condition of asymptotic decreasing of |Wf(s,u)| at  $s \to 0$ . Thus, the decreasing of wavelet-transformation amplitude depending on the scale is connected with uniform and pointed smoothness of Lipshits signal. Inequality (5) can be rewrited:

$$\log_2 |Wf(s,u)| \le \log_2 A + \left(\alpha + \frac{1}{2}\right) \log_2 s. (6)$$

Lipshits indexes can be arbitrarily changed from point to point. To characterize the smoothness f at point v is rather difficult because f can have different types of features presenting in the vicinity of point V. Zhaffar's theorem gives necessary and essential condition to wavelet transformation to estimate smoothness of Lipshits function f at point v.

Let wavelet  $\psi$  have *n* zero moments and *n* derivatives. If  $f \in L^2(R)$  satisfies Lipshits condition  $\alpha \le n$  at point *v*, then *A* exists that:

$$\forall (s,u) \in R^+ \times R,$$
$$\left| Wf(s,u) \right| \le A s^{\alpha + 1/2} \left( 1 + \left| \frac{u-v}{s} \right|^{\alpha} \right).$$
(7)

That's why when scale *s* is diminishing the amplitudes of wavelet coefficients have

fast diminishing till zero in the range where the signal is smooth.

Cone of influence of point v represents clearer interpretation of the condition [17].

If wavelet  $\psi$  has a compact carrier equal to [-C,C], then the majority of such points (s, u), that point contains v  $\psi_{us}(t) = s^{-1/2} \psi((t-u)/s)$ , in the carrier, and these points determine the cone of influence of point v of a large – scale surface. As the  $\psi((t-u)/s)$ carrier is equal to [u-Cs, u+Cs], then cone of influence v is defined by the inequality:

$$|u-v| \leq Cs$$
.

If *u* is in the cone of influence *v*, then  $Wf(s,u) = \langle f, \psi_{s,u} \rangle$  depends on value *f* in the vicinity of *v*. As  $|u-v|/s \le C$ , so the conditions (5) and (7) can be written in the form of:

$$\left| Wf(s,u) \right| \le A s^{\alpha + 1/2}, \tag{8}$$

what: is identical to uniform Lipshits condition.

Let's consider that function f in the vicinity of point v has an isolated feature, if |Wf(s,u)| doesn't satisfy the condition (8) in the vicinity of point v.

The results of work [17,3] are the following, if |Wf(s,u)| hasn't local maximums in small scales then f is a locally smooth function and the operation of singling out of isolated features of function f can be built by defining maximum values of function |Wf(s,u)| in small scales. Here it is necessary to take into account that while processing discrete data the smallest scale is limited by the step (pitch) of a discrete signal sample which is used during calculations.

When a feature is singled out there is a task to classify it.

Let's build the operation of classification of singled out features in a signal on the basis of inequalty (6) by the following way: Denote  $O_v(s,u)$  the line of maximums converging to point u-v, at  $s \to 0$ . For every such a point v determine slop angle  $\log_2 O_v(s,u)$  as function  $\log_2 s$ , at  $s \to 0$ :

$$\log_2 O_{\nu}(s, u) = \log_2 A + \left(\alpha + \frac{1}{2}\right) \log_2 s . (9)$$

Let's consider that we have a feature of  $\alpha$  at the point u = v.

Here it is necessary to take into account that the solution of the task to classify the peculiar feature depends on the basic function  $\psi$  properties. The set of features of a graphical signal received by such a way represents itself a pattern camera which can be used for its modification.

Experimental estimation and the analysis of the reaction of classification standard procedures on the feature of data presentation in the offered revealing procedure, their dependence on characteristics of processed signals presented in the form of large-scale decomposition structures and processed by means of wavelet analysis have been carried out in this research [4,5].

While carrying out the research of the revealing of additive noise characterized for a

number of digital cameras on the basis of a considered algorithm singling out for revealing isolated features of images has been done. Typical graphical patterns and maps of particular points which are characteristic to the formation image device have resulted of this performed research.

The cut off threshold of detailed coefficient close to optimum and the efficient decomposition depth equal to 4 has been chosen for data wavelet processing.

Checking, testing of the algorithm search for particular points in digital image which are characteristic to the device of its formation has been done on the basis of the following stages:

Receiving a great number of images from the camera forming the sample for design, construction of camera print.

The stage of camera print receiving on the basis of a great number of images from the identified camera of camera print. This stage includes the revealing from the print of pattern camera with the help of described filtration algorithm and its averaging by all prints from the sample premeditated for vector features formation.

The stage of image identification by camera pattern (Fig.).



Fig. Algorithm of camera identification by formed print

Camera	1	2	3	4	5	6	7	8
1	0.1364	0.0003	0 0018	0 0004	0.0017	0.0020	0.0030	0.0023
2	0.0004	0.1889	0.0002	0.0007	0.0004	0.0009	0.0000	0.0003
3	0.0035	0.0000	0.1727	0.0025	0.0042	0.0024	0.0044	0.0022
4	0 0004	0.0000	0.0015	0.1423	0.0006	0.0001	0.0016	0.0009
5	0.0005	0.0001	0.0010	0.0001	0.2645	0.0012	0.0010	O.0008
6	0.0009	0.0001	0.0004	0.0001	0.0005	0.479	0.0000	0.0012
7	0.0046	0.0001	0.0031	0.0018	0.0027	0.0029	0.1238	0.0017
8	0.0031	0.0002	0.0023	0.0015	0 0017	0.0032	0.0025	0.2005

Table. Values of averaging correlation coefficients results of received camera patterns

## **RESULTS OF RESEARCH**

Eight cameras model Nikon D5100 have been used for experimental checking of offered algorithm. 50 photos from each camera have been done for receiving camera prints. After singling out particular points the relationship of a number of such coincided points with a pattern received from the camera has been compared. The results of averaging correlation of received camera patterns are given in table. The coefficients of images and patterns received from the same camera are at the columns and lines intersection with the same indexes. Thus if the matrix with the help of which the image and the map of non uniformity coincides, the coefficient correlation value is 0.1 - 0.4 but at the coefficient correlation for non - coincided cameras it is 0.001 - 0.054.

As it has been stated while doing the experimental research similar regularities of coincided points the distribution in a pattern camera are kept for all researched cameras. Thus, on the basis of coincidences relationship we can come to the probable conclusion that researched photo belongs to a particular image formation device.

## CONCLUSIONS

1. Carried out research allowed us to single out and identify formations in digital

images (pictures) characteristic to the formation signal device.

2. The estimation of device identification authenticity on the basis of a proposed algorithm is satisfactory but not sufficient for the given algorithm usage as a part of a proved base.

3. Due to it is necessary to consider the ways to improve the proposed algorithm in further researches.

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### МЕТОД ИДЕНТИФИКАЦИИ АППАРАТУРЫ ЗАПИСИ ЦИФРОВЫХ ФОТОГРАФИЙ

#### Николай Сидоров, Евгений Белозеров

Аннотация. Предложен метод выявления в цифровом изображении изолированных особенностей, связанных с устройством его записи. Приведен алгоритм декомпозиции сигнала на вейвлет-анализа, выделены основе критерии идентификации изолированных особенностей в структуре изображения. Разработан алгоритм идентификации устройства записи цифровых изображений на основе использования выделенных изолированных особенностей. Проведено экспериментальное исследование оценки точности идентификации устройства записи цифровых изображений.

Ключевые слова: изображение, спектральные характеристики, вейвлет-разложение, изолированные особенности.

# Mathematical model of deformation of railway sleeper track structure with the step change of stiffness on the elastic winkler foundation of the constant stiffness

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Summary. We considered the formulation of the problem of constructing a mathematical model of the deformation of the railway sleeper track structure with the step change of stiffness on the elastic Winkler foundation. The rail is represented as a beam of variable cross-section. To determine the displacements and angles of rotation of cross sections, we used Laplace transform method of equation and delta at the joint. As a result of simulation, we obtained the forms for moving semi-infinite beams (stacked rails) laying on the elastic foundation, which can be used for arbitrary values of stiffness "C" of the elastic foundation. We also proposed a simplified alternate variant of solution using the method of "small" parameter in case if the stiffness characteristics of two adjacent rail sections slightly differ.

Key words: rolling stock, rail, linear stiffness, deflection and rotation angle of the cross-section at the joint, stiffness of the rail foundation, Winkler foundation.

## **INTRODUCTION**

An effective and long-term use of the equipment and the infrastructure, transport systems especially the railway transport. It can significantly reduce the maintenance costs of material flows moving through these systems [13, 14, 18, 19]. One of the methods to reduce

costs is to prolong the term of the rail work due to their constant permutation in the process of deterioration from more loaded onto less loaded routes [12, 17]. But in any case, such a movement involves the necessity of joining the rails of various grades, which leads to a drastic change in stiffness of the rail linear filament at the joint. This causes the significant vertical dynamic forces and, accordingly, decreases the velocity of railway vehicles. To avoid this phenomenon it is necessary to define the parameters of the deformation of the rail at the joint stiffness and the range of the rail foundation.

## **RESULTS OF RESEARCH**

The aim of the study is to determine the interaction between the wheels of railway vehicles and the rail with graded stiffness laying on the Winkler foundation.

To simplify the construction of the model we consider only one rail consisting of different types of rails and respectively different linear stiffness. The load from wheels of the railway vehicles is transferred to the rails and through ties to ballast which can be represented as Winkler foundation.

To describe the behaviour of the rail as the beam of variable linear stiffness, laying on the Winkler foundation, it is possible to use the differential equation that has the form [1, 7, 10, 16]:

$$EI_{2} \frac{d^{4}U^{2}(x)}{dx^{4}} + \left[C_{21} + (C_{22} - C_{21})_{-}\right]^{-} (x - x_{k}) \cdot U^{2}(x) =$$
  
=  $-\sum_{i=0}^{n+1} R_{i} \delta(x - x_{i}).$  (1)

The solution of the equation (1) with the classical approach is based on the dissection of the beam at the point  $x_k$  (the point of connection of two parts of the beam of different stiffness) and subsequent calculating of two semi-infinite beams laying on an elastic foundation of the constant stiffness (Fig. 1).

Consequent joining is at the same section  $x = x_k$ . When joining two sections of beams, in the section  $x_k$ , the compatibility of displacements and rotation angles of beams at the joint, should be observed, that is, the fulfilment of conditions:

$$\begin{array}{c}
U_{21}(x_k) = U_{22}(x_k), \\
\frac{dU_{21}}{dx}(x_k) = \frac{dU_{22}}{dx}(x_k).
\end{array}$$
(2)

To obtain the equation of bending of the beam (rail) laying on the elastic foundation (ballast) we use the equation of the initial parameters for each side.

To solve the equation for each side of the beam we use the method of integral transformation of Laplace's equation [3, 5, 10, 16]:

$$\frac{d^{4}U}{dx_{4}} + 4\alpha^{4}U = \frac{P_{i}}{E_{1}I_{1}} \cdot \delta(x - x_{i}), \qquad (3)$$

$$\frac{d^{4}U}{dx_{4}} + 4\alpha^{4}U = \frac{P_{i}}{E_{2}I_{2}} \cdot \delta(x_{i} - x), \qquad (4)$$

where:  $\alpha^4 = \frac{1}{4} \frac{K_2}{EI_2}$ ,  $K_2$  – stiffness of the elastic foundation (N/m<sup>2</sup>), E – the coefficient of the elasticity (N/m<sup>2</sup>),  $EI_{(1,2)}$  – stiffness of sides 1 and 2 of the rail beam (N/m<sup>2</sup>),  $\delta(x_i - x)$ 

- the delta function, defined at the point  $x_i$ .



Fig. 1. Scheme of variable section beams on the elastic foundation:

a – calculation scheme of the beam with a step change of the linear stiffness  $C_{21}, C_{22}$  on the elastic foundation;

b – calculation schemes of beams with the constant linear stiffness on the elastic foundation  $C_{21}, C_{22}$ 

If the coordinate system passes through a cross-section at the point x, from two semiinfinite beams (two rail sections of different stiffness), only one beam, which has less EI stiffness, can be viewed. This simplification is possible because ultimately it is necessary to know the movement of this side of the rail (beam) to choose the diagram of the rail track structure, which will provide the necessary stiffness of the bed and smooth bending of both sides of the beam, eliminate the appearance of additional dynamic loads from the wheel to the rail. According to fig. 1 that is the side of the beam with the stiffness  $C_{22}$ . Therefore, it is sufficient to consider only the equation (4).

After using the direct Laplace's equation [16]:

$$F(x) = \int_{0}^{\infty} e^{-st} U(t) dt .$$
 (5)

We obtain:

$$S^{4}F(s) - U(0)S^{3} - U'(0)S^{2} - U''(0)S^{2} - 4\alpha^{4}F(s) =$$
  
=  $\sum_{i} \frac{P_{i}}{EI}e^{-sx_{i}}.$  (6)

After some equations:

$$F(s) = U(0)\frac{S^{3}}{S^{4} + 4\alpha^{4}} + U'(0)\frac{S^{2}}{S^{4} + 4\alpha^{4}} + U''(0)\frac{S^{2}}{S^{4} + 4\alpha^{4}} + \sum_{i}\frac{P_{i}}{EI}e^{-sx_{i}}.$$
 (7)

To obtain the equation of the bending of the beam U(x), laying on the elastic Winkler foundation it is necessary to make the inverse Laplace transformation by the formula:

$$U(x) = \lim_{a \to \infty} \frac{1}{2\pi i} \cdot \int_{a-ib}^{a+ib} e^{xs} F(s) ds .$$
 (8)

Then obtain:

$$U(x) = U(0)\cos\alpha x \cdot ch\alpha x + + U'(0)\frac{1}{2\alpha}[sh\alpha x \cdot \cos\alpha x + ch\alpha x \cdot \sin\alpha x] + U''(0)\frac{1}{2\alpha^2}sh\alpha x \cdot \sin\alpha x + + U'''\frac{1}{4\alpha^3}[ch\alpha x \cdot \sin\alpha x + sh\alpha x \cdot \cos\alpha x] + + \frac{1}{4\alpha^3 EI}\sum_i P_i \begin{bmatrix} ch\alpha(x_i - x) \cdot \sin\alpha(x_i - x) - \\ -sh\alpha(x_i - x) \cdot \cos\alpha(x_i - x) \end{bmatrix}.$$
(9)

To simplify the function (9) we make the following change:

$$ch\alpha x \cdot \cos \alpha x = B_{1}(x),$$

$$\frac{1}{2\alpha}(ch\alpha x \cdot \sin \alpha x + sh\alpha x \cdot \cos \alpha x) = B_{2}(x),$$

$$\frac{1}{2\alpha^{2}}(sh\alpha x \cdot \sin \alpha x) = B_{3}(x),$$

$$\frac{1}{4\alpha^{3}}(ch\alpha x \cdot \sin \alpha x - sh\alpha x \cdot \cos \alpha x) = B_{4}(x).$$
(10)

Then it can be written as:

$$U(x) = U(0) \cdot B_1(x) + U'(0) \cdot B_2(x) + U''(0) \cdot B_3(x) + U'''(0) \cdot B_4(x) + \frac{1}{EI} \sum_i P_i B_4(x_i - x),$$
(11)

at that:

$$B_4(x_i - x) = \begin{cases} B_4(x_i - x) \text{ if } x_i \ge x, \\ 0 & \text{ if } x_i \le x. \end{cases}$$
(12)

Using the coupling between the shear forces and moments at the point of connection of beams (rails) of different stiffness, as well as derivatives of the displacement of the beam it allows determining the above-mentioned moments and forces:

$$M(x) = -EI \frac{d^2 U(x)}{dx^2} \to M(0) = -EI \cdot U''(0),$$
  

$$Q(x) = -EI \frac{d^3 U(x)}{dx^3} \to Q(0) = -EI \cdot U''(0).$$
(13)

Using the equation (13) the expression for bending of the beam (11) can be transformed to the form:

$$U(x) = U(0) \cdot B_{1}(x) + U'(0) \cdot B_{2}(x) + \frac{1}{EI} \left[ -M(0) \cdot B_{3}(x) - Q(0) \cdot B_{4}(x) + \sum_{i} P_{i}B_{4}(x_{i} - x) \right].$$
(14)

Arbitrary constants

U(0), U'(0), M(0), Q(0), in the equation (14) can be determined from the boundary conditions.

As stated above, if we cut the beam of the variable stiffness at the point of connection

of the semi-infinite stiffness  $C_{21}$  and  $C_{22}$ , i.e., at the cross section  $x = x_k$  (Fig. 1), and laying on the elastic foundation of the constant stiffness, for calculating each of these beam it is possible to use the equation (14). For that the origin of coordinates should be placed at the joint between the beams and put new variables along the axes of beams  $x_1$  and  $x_2$ , which are connected with the initial (basic) coordinate system by the following ratio:

$$x_1 = x_k - x; \ x_2 = x - x_k$$
. (15)

For the semi-infinite beam with the lower stiffness  $C_{22}$  (Fig. 1), the equation (14) takes the form:

$$U_{22}(x_2) = U(0) \cdot B_1(x_2) + U'(0) \cdot B_2(x_2) + \frac{1}{EI_2} \left[ -M(0) \cdot B_3(x_2) - Q(0) \cdot B_4(x_2) + \sum_i P_i^{22} B_4(x_2 - x_2^i) \right].$$
(16)

For the second semi-infinite beam (rail) of the higher stiffness  $C_{21}$  (Fig. 1), the equation (14) takes the form:

$$U_{21}(x_2) = U(0) \cdot B_1(x_1) + U'(0) \cdot B_2(x_1) + \frac{1}{EI_1} \left[ -M(0) \cdot B_3(x_1) - Q(0) \cdot B_4(x_2) + \sum_i P_i^{21} B_4(x - x_1^i) \right].$$
(17)

Arbitrary constants U(0), U'(0) for the semi-infinite beam are determined from the condition that is at large values of x, which they are derived; movements should be zero [15]. Where  $x \to \infty$ ,  $ch\alpha x \to sh\alpha x \to \frac{1}{2}e^{\alpha x}$ .

Using the equation (10) after the transformation we obtain the following:

$$\begin{cases} B_{3}(x) \rightarrow \frac{1}{2} e^{\alpha x} (\cos \alpha x), \\ B_{2}(x) \rightarrow \frac{1}{4\alpha} e^{\alpha x} (\sin \alpha x + \cos \alpha x), \\ B_{3}(x) \rightarrow \frac{1}{4\alpha^{2}} e^{\alpha x} (\sin \alpha x + \cos \alpha x), \\ B_{4}(x) \rightarrow \frac{1}{4\alpha^{2}} e^{\alpha x} (\sin \alpha x - \cos \alpha x), \\ and \ if \ x = (x - x^{i}), \\ B_{4}(x)(x - x^{i}) \rightarrow \frac{1}{8\alpha^{3}} e^{\alpha (x - x^{i})} [\sin \alpha (x - x^{i}) - \cos \alpha (x - x^{i})]. \end{cases}$$

$$(18)$$

Using (18) the equation of the deflection of the beam (14) we reduce to the form:

$$U(x \to \infty) = \frac{1}{2} e^{\alpha x} \left\{ \left\{ \cos^{\alpha x} \cdot \left\{ U(0) + U'(0) \frac{1}{2\alpha} + \frac{1}{EI} \times \left[ \frac{Q(0)}{4\alpha^3} - \sum_i \frac{P_i e^{-\alpha x^i}}{4\alpha^3} \left( \sin \alpha x^i + \cos \alpha x^i \right) \right] \right\} + \sin \alpha x \times \left\{ U'(0) \frac{1}{2\alpha} + \frac{1}{EI} \cdot \left[ -\frac{Q(0)}{4\alpha^3} - \frac{M(0)}{2\alpha^2} \times \left[ \times \sum_i \frac{P_i e^{-\alpha x^i}}{4\alpha^3} \left( \cos \alpha x^i + \sin \alpha x^i \right) \right] \right\} \right\} \to 0.$$
(19)

If the coefficients of the functions  $\sin \alpha x$ and  $\cos \alpha x$  at (19) are zero, displacements  $U(x \rightarrow \infty)$  become zero.

To ensure this condition from the equation (19) it is necessary to allocate and make zero of two following equations:

$$\begin{cases} U(0) + U'(0)\frac{1}{2\alpha} + \frac{1}{EI} \times \\ \times \left[\frac{Q(0)}{4\alpha^3} - \sum_i \frac{P_i e^{-\alpha x^i}}{4\alpha^3} \left(\sin \alpha x^i + \cos \alpha x^i\right)\right] = 0, \\ U'(0) + U'(0)\frac{1}{2\alpha} + \frac{1}{EI} \times \\ \times \left[-\frac{Q(0)}{4\alpha^3} - \frac{M(0)}{2\alpha^2} \sum_i \frac{P_i e^{-\alpha x^i}}{4\alpha^3} \left(\cos \alpha x^i + \sin \alpha x^i\right)\right] = 0. \end{cases}$$

$$(20)$$

By solving the system of equations (20), we obtain the expression for determining the unknown initial parameters U(0) and U'(0) in the general form:

$$\begin{cases} U(0) = \frac{1}{EI} \cdot \left[ \frac{Q(0)}{2\alpha^3} - \frac{M(0)}{2\alpha^2} + \sum_i \frac{P_i e^{-\alpha x^i}}{2\alpha^3} \cos \alpha x^i \right], \\ U'(0) = \frac{1}{EI} \cdot \left[ -\frac{Q(0)}{2\alpha^2} - \frac{M(0)}{\alpha} - \sum_i \frac{P_i}{2\alpha^2} (\cos \alpha x^i + \sin \alpha x^i) \right]. \end{cases}$$
(21)

Using the equation (21) and the data of the scheme (Fig. 1) for the beam with a lower linear stiffness  $C_{22}$  we obtain:

$$\begin{cases} U_{22}(0) = \frac{1}{EI_2} \cdot \begin{bmatrix} -\frac{Q(0)}{2\alpha_{22}^3} - \frac{M(0)}{2\alpha_{22}^2} + \\ +\sum_i \frac{P_i^{22} e^{-\alpha_{22} x_2^j}}{2\alpha_{22}^3} \cos \alpha_{22} x_2^i \end{bmatrix}, \quad (22) \\ U_{22}'(0) = \frac{1}{EI_2} \cdot \begin{bmatrix} \frac{Q(0)}{2\alpha_{22}^2} + \frac{M(0)}{2\alpha_{22}} - \\ -\sum_i \frac{P_i^{22} e^{-\alpha_{22} x_2^j}}{2\alpha_{22}^2} (\cos \alpha_{22} x_2^i - \sin \alpha_{22} x_2^i) \end{bmatrix}. \end{cases}$$

For beams with a higher linear stiffness  $C_{21}$  the equation will be of the form:

$$\begin{cases} U_{21}(0) = \frac{1}{EI_{1}} \cdot \begin{bmatrix} -\frac{Q(0)}{2\alpha_{21}^{3}} - \frac{M(0)}{2\alpha_{21}^{2}} + \\ +\sum_{i} \frac{P_{i}^{21} e^{-\alpha_{2} x_{1}^{i}}}{2\alpha_{21}^{3}} \cos \alpha_{21} x_{1}^{i} \end{bmatrix}, \\ -U_{21}^{\prime}(0) = \frac{1}{EI_{1}} \cdot \begin{bmatrix} \frac{Q(0)}{2\alpha_{21}^{2}} + \frac{M(0)}{2\alpha_{21}} - \\ -\sum_{i} \frac{P_{i}^{21} e^{-\alpha_{2} x_{1}^{i}}}{2\alpha_{21}^{2}} \left( \cos \alpha_{21} x_{1}^{i} - \sin \alpha_{22} x_{1}^{i} \right) \end{bmatrix}.$$
(23)

After making some changes, we obtain:

$$\begin{array}{l} \varphi_{21}^{i} = \frac{1}{\alpha_{21}^{3}} e^{-\alpha_{21} x_{1}^{i}} \cos \alpha_{21} x_{1}^{i}, \\ q_{21}^{i} = \frac{1}{\alpha_{21}^{2}} e^{-\alpha_{21} x_{1}^{i}} \left( \cos \alpha_{21} x_{1}^{i} - \sin \alpha_{21} x_{1}^{i} \right), \\ \varphi_{22}^{i} = \frac{1}{\alpha_{22}^{2}} e^{-\alpha_{22} x_{2}^{i}} \cos \alpha_{22} x_{2}^{i}, \\ q_{22}^{i} = \frac{1}{\alpha_{22}^{2}} e^{-\alpha_{22} x_{2}^{i}} \left( \cos \alpha_{22} x_{2}^{i} - \sin \alpha_{22} x_{2}^{i} \right). \end{array} \right\}$$

$$(24)$$

We can simplify the expressions (22 and 23):

$$\begin{cases} U_{22}(0) = \frac{1}{EI_2} \cdot \left[ -\frac{Q(0)}{2\alpha_{22}^3} - \frac{M(0)}{2\alpha_{22}^2} - \sum_i \frac{1}{2} P_i^{22} \cdot \varphi_{22}^i \right], \quad (25) \\ U_{22}'(0) = \frac{1}{EI_2} \cdot \left[ \frac{Q(0)}{2\alpha_{22}^2} + \frac{M(0)}{2\alpha_{22}} + \sum_i \frac{1}{2} P_i^{22} \cdot \varphi_{22}^i \right]. \\ \begin{cases} U_{21}(0) = \frac{1}{EI_1} \cdot \left[ -\frac{Q(0)}{2\alpha_{21}^3} - \frac{M(0)}{2\alpha_{21}^2} - \sum_i \frac{1}{2} P_i^{21} \cdot \varphi_{21}^i \right], \\ -U_{21}'(0) = \frac{1}{EI_1} \cdot \left[ \frac{Q(0)}{2\alpha_{21}^2} + \frac{M(0)}{2\alpha_{21}} + \sum_i \frac{1}{2} P_i^{21} \cdot \varphi_{21}^i \right]. \end{cases} \end{cases}$$

Here  $U_{21}(0)$ ,  $U'_{21}(0)$ ,  $U_{22}(0)$ ,  $U''_{22}(0)$  – displacements and rotation angles as derivatives of the from  $U_{ij}$  of both parts of the beams (Fig. 1) at their joints.

Proceeding from the conditions of the equality of displacements U(0) and rotation angles U'(0), we can determine the initial parameters Q(0) and M(0) in (22, 23) at the joint of two semi-infinite beams.

From the conditions of compatibility in the adopted coordinate systems:

$$\begin{cases} U_{21}(0) = U_{22}(0), \\ -U_{21}'(0) = U_{22}'(0). \end{cases}$$
(27)

After changing values  $U_{21}(0)$ ,  $U_{22}(0)$ , and also  $U'_{21}(0)$ ,  $U'_{22}(0)$  for expressions from (25, 26) and substituting in (27) we obtain:

$$\begin{cases} \mathcal{Q}(0) \left( \frac{1}{\alpha_{21}^{3}} + \frac{1}{\alpha_{22}^{3}} \right) - M(0) \left( \frac{1}{\alpha_{21}^{2}} + \frac{1}{\alpha_{22}^{2}} \right) = \\ = \sum_{i=0}^{S} P_{i}^{21} \cdot \varphi_{21}^{i} - \sum_{i=S+x}^{n+1} P_{i}^{22} \cdot \varphi_{22}^{i}, \\ \mathcal{Q}(0) \left( \frac{1}{\alpha_{21}^{2}} + \frac{1}{\alpha_{22}^{2}} \right) - M(0) \left( \frac{1}{\alpha_{21}} + \frac{1}{\alpha_{22}} \right) = \\ = \sum_{i=0}^{S} P_{i}^{21} \cdot q_{21}^{i} - \sum_{i=S+x}^{n+1} P_{i}^{22} \cdot q_{22}^{i}. \end{cases}$$
(28)

We made an additional replacement:

$$\left(\frac{1}{\alpha_{21}^3} + \frac{1}{\alpha_{22}^3}\right) = G_{11},$$

$$\left(\frac{1}{\alpha_{21}^2} + \frac{1}{\alpha_{22}^2}\right) = G_{12}, \left(\frac{1}{\alpha_{21}} + \frac{1}{\alpha_{22}}\right) = G_{22},$$

$$G_{11} \cdot G_{22} - G_{12}^2 = \Delta, \quad (29)$$

and solved the combined equations (28), taking into account the substitutions (29) relative to Q(0) and M(0) we get initial parameters which are explicitly expressed by concentrated forces  $P_i^{21}$  and  $P_i^{22}$ :

$$\begin{cases} \mathcal{Q}(0) = \frac{1}{\Delta} \cdot \left[ \sum_{i=0}^{S} P_i^{21} (G_{22} \varphi_{21}^i - G_{12} g_{21}^i) - \right] \\ - \sum_{i=S+x}^{n+1} P_i^{22} (G_{22} \varphi_{22}^i - G_{12} g_{22}^i) \\ \mathcal{M}(0) = \frac{1}{\Delta} \cdot \left[ \sum_{i=0}^{S} P_i^{21} (G_{12} \varphi_{21}^i - G_{11} g_{21}^i) - \right] \\ - \sum_{i=S+x}^{n+1} P_i^{22} (G_{12} \varphi_{22}^i - G_{11} g_{22}^i) \\ \end{bmatrix}.$$

$$(30)$$

Substituting the initial parameters Q(0) and M(0) from (30) to (25 and 26) and performing some transformations we obtain:

$$\begin{split} U_{22}(0) &= \frac{1}{2EI_{2}\Delta} \cdot \left\{ \sum_{i=1}^{2^{2}} \left[ -\varphi_{2}^{i} \left( \frac{G_{22}}{\alpha_{22}} + \frac{G_{12}}{\alpha_{22}} \right) + q_{22}^{i} \left( \frac{G_{12}}{\alpha_{22}} + \frac{G_{11}}{\alpha_{22}} \right) \right] \right\} + (31) \\ &+ \sum_{i=1}^{2^{2}} \left[ \varphi_{22}^{i} \left( \frac{G_{22}}{\alpha_{22}} + \frac{G_{12}}{\alpha_{22}} - \Delta \right) + q_{21}^{i} \left( \frac{G_{12}}{\alpha_{22}} + \frac{G_{11}}{\alpha_{22}} \right) \right] \right\}, \\ U_{22}^{i}(0) &= \frac{1}{2EI_{2}\Delta} \left\{ \sum_{i=1}^{2^{2}} \left[ \varphi_{21}^{i} \left( \frac{G_{22}}{\alpha_{22}} + \frac{2G_{12}}{\alpha_{22}} \right) - q_{21}^{i} \left( \frac{G_{12}}{\alpha_{22}} + \frac{2G_{11}}{\alpha_{22}} \right) \right] \right\}, \\ \sum_{i=1}^{2^{2}} \left[ -\varphi_{22}^{i} \left( \frac{G_{22}}{\alpha_{22}} + \frac{2G_{12}}{\alpha_{22}} - \Delta \right) - q_{22}^{i} \left( \frac{G_{12}}{\alpha_{22}} + \frac{2G_{11}}{\alpha_{22}} - \Delta \right) \right] \right\}. \\ U_{21}^{i}(0) &= \frac{1}{2EI_{1}\Delta} \cdot \left\{ \sum_{i=1}^{2^{2}} \left[ \varphi_{21}^{i} \left( \frac{G_{22}}{\alpha_{21}} - \frac{G_{12}}{\alpha_{21}} - \Delta \right) - q_{21}^{i} \left( \frac{G_{12}}{\alpha_{22}} + \frac{G_{11}}{\alpha_{22}} \right) \right] \right\}, \\ U_{21}^{i}(0) &= \frac{1}{2EI_{1}\Delta} \cdot \left\{ \sum_{i=1}^{2^{2}} \left[ \varphi_{21}^{i} \left( \frac{G_{22}}{\alpha_{21}} - \frac{G_{12}}{\alpha_{21}} - \Delta \right) - q_{21}^{i} \left( \frac{G_{12}}{\alpha_{21}} + \frac{G_{11}}{\alpha_{22}} \right) \right] \right\}, \\ U_{21}^{i}(0) &= \frac{1}{2EI_{1}\Delta} \cdot \left\{ \sum_{i=1}^{2^{2}} \left[ -\varphi_{21}^{i} \left( \frac{G_{22}}{\alpha_{21}} - \frac{G_{12}}{\alpha_{21}} - \frac{G_{12}}{\alpha_{21}} \right) + q_{21}^{i} \left( \frac{G_{12}}{\alpha_{22}} - \frac{2G_{11}}{\alpha_{21}} \right) \right] \right\}, \\ U_{21}^{i}(0) &= \frac{1}{2EI_{1}\Delta} \left\{ \sum_{i=1}^{2^{2}} \left[ -\varphi_{21}^{i} \left( \frac{G_{22}}{\alpha_{21}} - \frac{2G_{12}}{\alpha_{21}} \right) + q_{21}^{i} \left( \frac{G_{12}}{\alpha_{22}} - \frac{2G_{11}}{\alpha_{21}} \right) \right] \right\}. \\ (32)$$

For simplicity, we are making the replacement:

$$\begin{cases} U_{21,1}^{i} = \frac{1}{2\Delta} \left[ \varphi_{21}^{i} \left( \frac{G_{22}}{\alpha_{21}^{3}} - \frac{G_{12}}{\alpha_{21}^{2}} - \Delta \right) - q_{21}^{i} \left( \frac{G_{12}}{\alpha_{21}^{3}} + \frac{G_{11}}{\alpha_{21}^{3}} \right) \right], \\ U_{21,2}^{\prime} = \frac{1}{2\Delta} \left[ -\varphi_{21}^{i} \left( \frac{G_{22}}{\alpha_{21}^{3}} - \frac{G_{12}}{\alpha_{21}^{2}} \right) - q_{22}^{i} \left( \frac{G_{12}}{\alpha_{21}^{3}} + \frac{G_{11}}{\alpha_{21}^{2}} \right) \right]. \end{cases}$$
(33)

$$\begin{cases} U_{22,2}^{i} = \frac{1}{2\Delta} \left[ -\varphi_{21}^{i} \left( \frac{G_{22}}{\alpha_{22}^{3}} + \frac{G_{12}}{\alpha_{22}^{2}} \right) + q_{21}^{i} \left( \frac{G_{12}}{\alpha_{22}^{3}} + \frac{G_{11}}{\alpha_{22}^{3}} \right) \right], \\ U_{22,2}^{\prime} = \frac{1}{2\Delta} \left[ -\varphi_{22}^{i} \left( \frac{G_{22}}{\alpha_{22}^{3}} - \frac{G_{12}}{\alpha_{22}^{2}} - \Delta \right) + q_{22}^{i} \left( \frac{G_{12}}{\alpha_{22}^{3}} + \frac{G_{11}}{\alpha_{22}^{2}} \right) \right]. \end{cases}$$
(34)  
$$\begin{cases} U_{21,1}^{i} = \frac{1}{2\Delta} \left[ -\varphi_{21}^{i} \left( \frac{G_{22}}{\alpha_{22}^{2}} + \frac{G_{12}}{\alpha_{22}} \right) + q_{21}^{i} \left( \frac{G_{12}}{\alpha_{21}^{2}} - \frac{2G_{11}}{\alpha_{21}} + \Delta \right) \right], \\ U_{21,2}^{\prime} = \frac{1}{2\Delta} \left[ \varphi_{22}^{i} \left( \frac{G_{22}}{\alpha_{21}^{2}} - \frac{G_{12}}{\alpha_{21}^{2}} \right) - q_{22}^{i} \left( \frac{G_{12}}{\alpha_{21}^{2}} + \frac{2G_{11}}{\alpha_{21}} \right) \right]. \end{cases}$$
(35)

Also in the formulas (30):  

$$Q_{21}^{i} = \frac{1}{\Delta} \Big( G_{22} \varphi_{21}^{i} - G_{12} \varphi_{21}^{i} \Big); \quad {}^{i}_{22} = \frac{1}{\Delta} \Big( -G_{22} \varphi_{22}^{i} - G_{12} \varphi_{22}^{i} \Big), \quad (36)$$

$$M_{21}^{i} = \frac{1}{\Delta} \Big( G_{12} \varphi_{21}^{i} - G_{11} \varphi_{21}^{i} \Big); \quad M_{22}^{i} = \frac{1}{\Delta} \Big( -G_{12} \varphi_{22}^{i} - G_{11} \varphi_{22}^{i} \Big).$$
(37)

Substituting in (30) we obtained simplified expressions from (36, 37) designations for initial parameters U(0), U'(0), Q(0), M(0):

$$Q(0) = \sum_{i=0}^{S} P_i^{21} Q_{21}^i + \sum_{i=S+1}^{n+1} P_i^{22} Q_{22}^i,$$
(38)
$$M(0) = \sum_{i=0}^{S} P_i^{21} Q_{21}^i + \sum_{i=S+1}^{n+1} P_i^{22} M^i$$

 $M(0) = \sum_{i=0}^{i} P_i^{2i} Q_{21}^i + \sum_{i=S+1}^{i} P_i^{2i} M_{22}^i.$ Similarly, transforming (25 and 26),

using (33-37) we obtain:

$$\begin{cases} U_{21}(0) = \frac{1}{EI_{1}} \left[ \sum_{i=0}^{S} P_{i}^{21} U_{21,1}^{i} + \sum_{i=S+1}^{n+1} P_{i}^{22} U_{21,2}^{i} \right], \\ U_{22}(0) = \frac{1}{EI_{2}} \left[ \sum_{i=0}^{S} P_{i}^{21} U_{22,1}^{i} + \sum_{i=S+1}^{n+1} P_{i}^{22} U_{22,2}^{i} \right]. \end{cases}$$
(39)
$$\begin{cases} U_{21}'(0) = \frac{1}{EI_{1}} \left[ \sum_{i=0}^{S} P_{i}^{21} U_{21,1}^{\prime i} + \sum_{i=S+1}^{n+1} P_{i}^{22} U_{21,2}^{\prime i} \right], \\ U_{22}'(0) = \frac{1}{EI_{2}} \left[ \sum_{i=0}^{S} P_{i}^{21} U_{22,1}^{\prime i} + \sum_{i=S+1}^{n+1} P_{i}^{22} U_{22,2}^{\prime i} \right]. \end{cases}$$
(40)

Results of the transformation the equations (38-40) allow to represent all the initial parameters of two semi-infinite rigidly coupled of different stiffness beams laying on the elastic foundation via concentrated forces  $P_i^{21}$ ,  $P_i^{22}$ , acting from the railway vehicles.

From the condition of the compatibility of displacements (27) the expression  $U_{21}(0) = U_{22}(0)$ ,  $-U'_{21} = U'_{22}$  is hold and used in further calculations.

Using the desired expression (16, 17) for the displacement of two semi-infinite beams which are rigidly connected and have different stiffness in the unfolded state, with regard to (38-40), we obtain:

$$U_{21}(x_{1}) = \frac{1}{EI_{1}} \left\{ \sum_{i=0}^{S} P_{i}^{21} \left[ \left( U_{21,1}^{i} \cdot B_{1}(x_{1}) - U_{21,1}^{\prime i} \cdot B_{2}(x_{1}) - M_{21}^{\prime i} \cdot B_{3}(x_{1}) + Q_{21}^{i} \cdot B_{4}(x_{1}) \right) \right]_{-} \right]^{-} \\ - M_{21}^{\prime i} \cdot B_{3}(x_{1}) + Q_{21}^{i} \cdot B_{4}(x_{1}) \right]_{-} \left]^{-} (x_{1} - x_{i}) + \\ + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left( U_{21,2}^{i} \cdot B_{1}(x_{1}) - U_{21,1}^{\prime i} \cdot B_{2}(x_{1}) - M_{22}^{\prime i} \cdot B_{3}(x_{1}) + Q_{22}^{\prime i} \cdot B_{4}(x_{1}) \right) \right]_{-} \right]^{-} (x_{1} - 0) \right\}.$$

$$(41)$$

$$U_{22}(x_{2}) = \frac{1}{EI_{2}} \left\{ \sum_{i=0}^{S} P_{i}^{21} \left[ \left( U_{22,1}^{i} \cdot B_{1}(x_{2}) - U_{22,1}^{\prime i} \cdot B_{2}(x_{2}) - M_{21}^{\prime i} \cdot B_{3}(x_{2}) + Q_{21}^{\prime i} \cdot B_{4}(x_{2}) \right) \right]_{-} \right]^{-} (x_{2} - 0) + \\ + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left( \left( U_{22,2}^{i} \cdot B_{1}(x_{2}) - U_{22,2}^{\prime i} \cdot B_{2}(x_{2}) \right) - M_{22,2}^{\prime i} \cdot B_{2}(x_{2}) \right) \right]_{-} \right]^{-}$$

$$-M_{22}^{\prime i} \cdot B_{3}(x_{2}) + Q_{22}^{\prime i} \cdot B_{4}(x_{2})) \Big|_{-} \Big|^{-} (x_{2} - 0) - B_{4} \Big( x_{2} - x_{2}^{i} \Big)_{-} \Big|^{-} \Big( x_{2} - x_{2}^{i} \Big) \Big\}.$$
(42)

When passing from the local to the global coordinate system in Heaviside record step function making changes using the expression  $x_1 = x_k - x$ ;  $x_2 = x - x_k$  and regulations:

$$| {}^{-}(x_{k} - x) = \begin{cases} 1, at \quad \tilde{o} \leq \tilde{o}_{k}, \\ 0, at \quad \tilde{o} \geq \tilde{o}_{k}; \end{cases}$$

$$| {}^{-}(x^{i} - x) = \begin{cases} 1, at \quad \tilde{o} \leq \tilde{o}^{i}, \\ 0, at \quad \tilde{o} \geq \tilde{o}^{i}. \end{cases}$$

$$(43)$$

Making the transfer of the equation (41, 42) to the global coordinate system x we are taking to the account the expressions in [2]:

$$U_{21}(x_{1}) = \frac{1}{EI_{1}} \left\{ \sum_{i=0}^{S} P_{i}^{21} \left[ \left[ U_{211}^{i} \cdot B_{1}(x_{k} - x) - U_{211}^{\prime i} \cdot B_{2}(x_{k} - x) - - M_{21}^{\prime i} \cdot B_{3}(x_{k} - x) + Q_{21}^{i} \cdot B_{4}(x_{k} - x) \right] \right] \right]^{-} (x_{k} - x) - - B_{4} \left[ x^{i} - x \right] - \left[ - \left[ x^{i} - x \right] + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{212}^{i} \cdot B_{1}\left( x^{i} - x \right) - - U_{211}^{\prime i} \cdot B_{2}\left( x^{i} - x \right) - M_{22}^{\prime i} \cdot B_{3}\left( x^{i} - x \right) + Q_{22}^{\prime i} \cdot B_{4}\left( x^{i} - x \right) \right] \right]^{-} \left[ (x^{i} - x) \right] = \left[ - \left[ x^{i} - x \right] + \left[ x^{i} - x \right] \right] \right]^{-} \left[ (x^{i} - x) \right] = \left[ x^{i} - x \right] = \left[ x^{i} - x^{i} - x \right] = \left[ x^{i} - x \right] = \left[ x^{i} - x^{i} - x^{i} - x^{i} - x^{i} - x^{i} \right] = \left[ x^{i} - x^{i} + x^{i} - x^{i} - x^{i} + x^{i} - x^{i} + x^{i$$

$$U_{22}(x_{2}) = \frac{1}{EI_{2}} \left\{ \sum_{i=0}^{S} P_{i}^{21} \left[ \left[ U_{22,1}^{i} \cdot B_{1}(x - x_{k}) - U_{22,1}^{i} \cdot B_{2}(x - x_{k}) - M_{21}^{i} \cdot B_{3}(x - x_{k}) + Q_{21}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \right]^{-} \\ \left( x - x_{k} \right) + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{1}(x - x_{k}) - U_{22,2}^{i} \cdot B_{2}(x - x_{k}) - M_{22}^{i} \cdot B_{3}(x - x_{k}) + Q_{22}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \right]^{-} \\ \left( x - x_{k} \right) + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{1}(x - x_{k}) - U_{22,2}^{i} \cdot B_{2}(x - x_{k}) - M_{22}^{i} \cdot B_{3}(x - x_{k}) + Q_{22}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \right]^{-} \\ \left( x - x_{k} \right) + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{1}(x - x_{k}) - U_{22,2}^{i} \cdot B_{2}(x - x_{k}) - H_{22}^{i} \cdot B_{3}(x - x_{k}) + Q_{22}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \right]^{-} \\ \left( x - x_{k} \right) + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{1}(x - x_{k}) - U_{22,2}^{i} \cdot B_{2}(x - x_{k}) - H_{22}^{i} \cdot B_{3}(x - x_{k}) + Q_{22}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \right]^{-} \\ \left( x - x_{k} \right) + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{4}(x - x_{k}) - H_{22}^{i} \cdot B_{3}(x - x_{k}) + H_{22}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \right]^{-} \\ \left( x - x_{k} \right) + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \right]^{-} \\ \left( x - x_{k} \right) + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \right]^{-} \\ \left( x - x_{k} \right) + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \right]^{-} \\ \left( x - x_{k} \right) + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \right]^{-} \\ \left( x - x_{k} \right) + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \right]^{-} \\ \left( x - x_{k} \right) + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \\ \left( x - x_{k} \right] + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \\ \left( x - x_{k} \right] + \sum_{i=S+1}^{n+1} P_{i}^{22} \left[ \left[ U_{22,2}^{i} \cdot B_{4}(x - x_{k}) \right] \right] \\ \left( x - x_{k} \right]$$

When transferring the force P along the rail (beam) of the variable stiffness laying on an elastic foundation (i.e., rolling the wheels of the rolling stock), from semi-infinite beam section with higher stiffness to the section with less stiffness, after the load jump the perturbation is damped with the increasing distance from the considered cross section at the point  $x_k$  to the infinity.

According to these equations (43) and (44) of the function  $B_1(x)$ ..... $B_4(x)$ , taking into account that the fading should be of the following form:

$$\begin{vmatrix}
B_{1}(x) \rightarrow \frac{1}{2}e^{-\alpha x}(\cos \alpha x), \\
B_{2}(x) \rightarrow \frac{1}{4\alpha}e^{-\alpha x}(\sin \alpha x - \cos \alpha x), \\
B_{3}(x) \rightarrow \frac{1}{4\alpha^{2}}e^{-\alpha x}(\sin \alpha x - \cos \alpha x), \\
B_{4}(x) \rightarrow \frac{1}{8\alpha^{3}}e^{-\alpha x}(\sin \alpha x + \cos \alpha x) \text{ or} \\
B_{4}(x - x_{k}) \rightarrow \frac{1}{8\alpha^{3}}e^{-\alpha (x - x_{k})}[\sin \alpha (x - x_{k}) + \cos \alpha x - x_{k}].
\end{cases}$$
(46)

Using Krylov's functions we obtain the equation of the deformation parameters of the beam with the damped oscillations, taking into account [9]:

$$U(x) = U(0)ch\alpha x \cdot \cos\alpha x + + U'(0)\frac{1}{2\alpha}[ch\alpha x \cdot \sin\alpha x + sh\alpha x \cdot \cos\alpha x] + + U''(0)\frac{1}{2\alpha^2}sh\alpha x \cdot \sin\alpha x + + U'''(0)\frac{1}{4\alpha^3}[ch\alpha x \cdot \sin\alpha x - sh\alpha x \cdot \cos\alpha x] + + \frac{P_i}{EI_2}\frac{1}{4\alpha^3}[ch\alpha (x - x_i) \cdot \sin\alpha (x - x_i) - - sh\alpha (x - x_i) \cdot \cos\alpha (x - x_i)].$$
(47)

And taking into account that  $ch\alpha x = \frac{1}{2}(e^{\alpha x} + e^{-\alpha x})$ ;  $sh\alpha x = \frac{1}{2}(e^{\alpha x} - e^{-\alpha x})$  it can be presented to the form with the lower stiffness for the semi-infinite beam:

$$U(x) = \frac{1}{2} e^{\alpha x} \left\{ U(0) \cos \alpha x + U'(0) \frac{1}{2\alpha} (\sin \alpha x + \cos \alpha x) + \right. \\ \left. + U''(0) \frac{1}{2\alpha^2} \sin \alpha x + U'''(0) \frac{1}{4\alpha^3} (\sin \alpha x - \cos \alpha x) + \right. \\ \left. + \frac{P_i}{EI_2} \frac{1}{4\alpha^3} \left[ e^{-\alpha x} (\sin \alpha x \cdot \cos \alpha x_i - \cos \alpha x \cdot \sin \alpha x_i) - \right. \\ \left. - e^{-\alpha x_i} (\cos \alpha x \cdot \sin \alpha x_i + \sin \alpha x \cdot \cos \alpha x_i) \right] \right\} + \\ \left. \frac{1}{2} e^{\alpha x} \left\{ U(0) \cos \alpha x + U'(0) \frac{1}{2\alpha} (\sin \alpha x - \cos \alpha x) + \right. \\ \left. + U''(0) \frac{1}{2\alpha^2} \sin \alpha x + U'''(0) \frac{1}{4\alpha^3} (\sin \alpha x + \cos \alpha x) + \right. \\ \left. + \frac{P_i}{EI_2} \frac{1}{4\alpha^3} \left[ e^{-\alpha x_i} (\sin \alpha x \cdot \cos \alpha x_i - \cos \alpha x \cdot \sin \alpha x_i) + \right. \\ \left. + e^{-\alpha x_i} (\cos \alpha x \cdot \cos \alpha x_i + \cos \alpha x \cdot \cos \alpha x_i) \right] \right\}.$$

$$(48)$$

With large values of x, while damping of amplitudes of displacements, expressions in braces (with multiplier  $e^{\alpha x}$ ) can be ignored because they are under common factors  $\sin \alpha x$  and  $\cos \alpha x$ . This condition is taken into account while obtaining the expression for U(0) and U'(0).

The expression containing the factor  $e^{\alpha x}$ , defines functions  $B_1(x)....B_4(x)$  and  $B_4(x-x_i)$  factors with the initial parameters U(0)...U'''(0)

and 
$$\frac{P_i}{EI_{1,2}}$$
.

Thus equations (44, 45) allow to define displacements of the beam of the variable stiffness, laying on the elastic foundation, which varies accordingly to the stepped law (Fig. 2). Also the data of the equation for a semi-infinite beams ensure that the conditions of compatibility of displacements (linear and angular) at the point of junction, where the abrupt change of their stiffness happens; equations (47, 48) obtained after transformation of the explicitly contain only external concentrated forces  $P_i$  that act from the side of railway vehicles.

The above expressions used for the displacing of the semi-infinite beam laying on the elastic foundation are valid for arbitrary values of stiffness C and the elastic foundation.



Fig. 2. Scheme of the loading and the displacement of the beam of variable stiffness  $C_{21}$  and  $C_{22}$  on the elastic foundation

In case, if the magnitude of the beam (rail)  $\Delta c$  is relatively small, it is convenient to use the method of the small parameter [6, 8, 11, 21], which allows to reduce the number of computations in determining the displacements of the beam on the elastic foundation. The differential equation describing the stress-strain state of the beam with the lower stiffness while it's spasmodic change, laying on the elastic foundation is:

$$EI_{2}\frac{d^{4}U^{2}}{dx^{4}} + c_{22}\left[1 + \varepsilon_{-}\right]^{-} (x - x_{k}) \cdot U^{2}(x) = -\sum P_{i}\delta(x - x_{i}), \quad (49)$$
  
where:  $\varepsilon = \frac{c_{21} - c_{22}}{c_{21} - c_{22}}$ .

Series expansion  $U^2(x)$  by the small parameter  $\varepsilon$  [6]

 $c_{22}$ 

$$U^{2}(x) = U_{0}^{2}(x) + \varepsilon U_{1}^{2}(x) + \varepsilon^{2} U_{2}^{2}(x).....,$$
(50)

By substituting the solution (50) into the equation (49) we obtain:

$$EI_{2} \frac{d^{4}U^{2}}{dx^{4}} \Big[ U^{2}(x) = U_{0}^{2}(x) + \varepsilon U_{1}^{2}(x) + \varepsilon^{2}U_{2}^{2}(x) + \dots \Big] + c_{2} \Big[ 1 + \varepsilon \Big|^{-} (x - x_{k}) \Big] \Big[ U^{2}(x) = U_{0}^{2}(x) + \varepsilon U_{1}^{2}(x) + \varepsilon^{2}U_{2}^{2}(x) + \dots \Big] = \sum P_{i} \delta(x - x_{k}).$$
(51)

By grouping the terms of the equation (51) by the degree  $\varepsilon^{j}$ , *j* we obtain:

$$\varepsilon^{0} \left[ EI_{2} \frac{d^{4}U_{0}^{2}}{dx^{4}} c_{2}U_{0}^{2}(x) + \sum_{i=0}^{n+1} P_{i}\delta(x-x_{k}) \right] + \varepsilon^{1} \left[ EI_{2} \frac{d^{4}U_{1}^{2}}{dx^{4}} + c_{2}U_{1}^{2}(x) + c_{2} - \left|^{-}(x-x_{k})\right| \right] + \varepsilon^{2} \left[ EI_{2} \frac{d^{4}U_{2}^{2}}{dx^{4}} c_{2}U_{2}^{2}(x) + c_{2} - \left|^{-}(x-x_{k})U_{1}^{2}(x)\right| + \dots = 0, \quad (52)$$

The expression with  $\varepsilon^{j}$  of different forces becomes zero. As a result, we obtain a system of differential equations:

$$\frac{d^{4}U_{0}^{2}}{dx^{4}} + 4\alpha^{4}U_{0}^{2}(x) = -\frac{1}{EI_{2}}\sum P_{i}\delta(x - x_{k}) = 0,$$

$$\frac{d^{4}U_{1}^{2}}{dx^{4}} + 4\alpha^{4}U_{1}^{2}(x) = -4\alpha^{4} | (x - x_{k})U_{0}^{2}(x),$$

$$\frac{d^{4}U_{2}^{2}}{dx^{4}} + 4\alpha^{4}U_{2}^{2}(x) = -4\alpha^{4} | (x - x_{k})U_{1}^{2}(x),$$
(53)

where:  $\alpha^4$  for the beam side with the lower stiffness:

$$\alpha^{4} = \frac{1}{4} \frac{c_2}{EI_2} \,. \tag{54}$$

The system of differential equations (53) is solving sequentially, beginning with the first equation of the system. The solution of the previous equation is included into the right side of the following equation, etc. [20].

Using expressions (44, 45) or (50) it is possible to sum the interaction of railway vehicles with the track structure, completed with rails of different brands (i.e. different linear stiffness), laying on the elastic foundation [4, 22].

Besides the classical approach of identifying the technical parameters of the deformation of the track panels laying on the elastic foundation with low values of the abrupt change of the stiffness of the rail the small parameter method can be used.

The purpose of this calculation (such an approach) is confirmed (checking) by the approach to the task solution of Winkler model as quiet simple and in many cases provides a good convergence with the practice.

It should be noted that the accuracy of determining the parameters of the permanent way, the method of calculations that was given above, essentially depends on the type of ties, which are the intermediate supports between the rail and under-rail space (ballast layer).

According to this while calculating it is necessary to make the definite assumption. For example, assuming that the load on the rail from the wheel of the rolling stock to the load of the transmitted to the resilient space, it means that the displacement of the boundary of the half-space can be determined by the formula:

$$U_{3}(x_{1}, x_{2}, 0) = \frac{1 - v}{2\pi G_{n}} \frac{p^{J}}{r}, \qquad (55)$$

where: v – Poisson's ratio,  $G_n$  – the modulus of stiffness of the half space,  $p^j$  – the load on the elastic half space from the track.

$$r^2 = x_1^2 + x_2^2 \,, \tag{56}$$

where:  $r(x_1, x_2)$  – the distance between the point of the application of the force  $p^j$  and the point of determining the displacement.

To improve the accuracy of the task solution, we take into account the interaction of the track support with the under-rail elastic half-space boundary. In this case it is necessary to move to a distributed load  $g_3(\xi_1,\xi_2)$ . The displacement of the border the border of the elastic half-space can be defined by the following dependency:

$$U_{3}(x_{1}, x_{2}, 0) = \frac{1 - \nu}{2\pi G_{n}} \int_{\Sigma} \int \frac{g_{3}^{i}(\xi_{1}, \xi_{2}) d\xi_{1}, d\xi_{2}}{r_{1}}, \quad (57)$$

where:  $\xi_1, \xi_2$  – coordinates of different points on the side with the distributed load  $g_3^j(\xi_1,\xi_2)$ ,  $r_1^2 = (x_1 - \xi_1)^2 + (x_2 - \xi_2)^2$ , at that  $r_1$ – (variable), the distance between different points  $(\xi_1, \xi_2)$  of the loaded side to the point, which displacement is determined by  $(x_1, x_2, x_3 = 0)$ .

Formulas from the given above techniques allow to describe (but in practice) simple types of rail connections with threedimensional space under-rail system. Despite bearing the rail on the elastic foundation and various analytical forms of description, the scheme of calculation remains general allows determining unchanged and the displacement of the rail track from work of concentrated forces  $p_3^j$  from the wheels of the vehicle. That is the part of an overall dual problem and requires taking into account the vertical displacement of the wheels of the railway vehicle and then maybe the solution of the dual task: railway vehicles, the track and the ballast.

#### CONCLUSIONS

1. We developed the generalized model of the adjoin formulation for the track and the elastic foundation with the load from the wheels of the railway vehicles, which allows to determine the stress-strain state in the component parts of a complex system.

2. The generalized model can be used in various designs of railway vehicles and different types of elastic foundation (simulated by Winkler foundation). We found the system of algebraic equations composed for the unknown forces of the wheel-rail interaction.

3. The result of the solution of the system of the linear equations interaction forces of the wheel-rail allow to make calculations of stresses, strains and displacements of all system components.

4. We developed a simplified model that allows (while operating on the rail system canvas of concentrated forces, on the rails) to determine the stress, the strain and the displacement of the rail (simulated infinite beam) on Winkler foundation with varying stiffness. It has two solutions. The first is based on the "conjugation" of two semiinfinite beams (rails) with a step change of stiffness on the elastic foundation. Such a solution of the task is "exact" and taking into account different stiffness values of connected rails. The basis of the second solution is the method of the "small" parameter. The given approach is effective when the stiffness characteristics of two adjacent sections slightly differ from one another.

5. To estimate the allowable using of generalized Winkler foundation we obtained analytical expressions of the displacements for the same options which were obtained for the elastic half-space.

6. The proposed generalized model of Winkler foundation allows effective solving of many important practical problems, including the problem of the deformation of the rail with the elastic half-space and choose its stiffness characteristics to reduce the vertical dynamic component of force generated while transition of the rail wheel with one stiffness on the rail with the other stiffness.

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#### МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ДЕФОРМАЦИИ РЕЛЬСОШПАЛЬНОЙ РЕШЕТКИ СО СТУПЕНЧАТЫМ ИЗМЕНЕНИЕМ ЖЕСТКОСТИ НА УПРУГОМ ВИНКЛЕРОВОМ ОСНОВАНИИ ПОСТОЯННОЙ ЖЕСТКОСТИ

#### Максим Слободянюк, Анна Никитина, Григорий Нечаев, Наталья Раковская

Аннотация. Рассмотрена постановка задачи построения математической модели деформации рельсошпальной решетки со ступенчатым изменением жесткости на упругом винклеровом основании. Рельсовая нить представлена в виде балки переменного сечения. Для определения перемещений и углов поворота сечений в месте стыковки использован метод преобразования уравнения Лапласа и функция Дирака. В результате получены выражения моделирования для перемещения полубесконечных балок (состыкованных рельсов), лежащих на упругом основании, которые могут быть использованы для произвольных значений жесткости «С» упругого основания. Предложен так же упрощенный вариант решения задачи с использованием метода «Малого» параметра для случая, когда жесткостные характеристики двух смежных участков рельса отличаются незначительно.

Ключевые слова: подвижной состав, рельс, линейная жесткость, прогиб и угол поворота сечения в месте стыка, жесткость подрельсового основания, винклерово основание.

## Multifractal approach in pattern recognition of an announcer's voice

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S u m m a r y. The research results on revealing of multi-fractal structures for vowel phonemes are given in this paper. The possibility to "construct" vowel phonemes from "atomic" phoneme structures by means of affixes transformations is shown. Multi-fractal conditions which allow designing voice individual characteristics are considered in this paper.

K e y w o r d s : self-similar structure, speech fragments, voice recognition, "atomic" components of phoneme fragments, phonemes, multi-fractal.

## **INTRODUCTION**

The researches in the field of automatic recognition of radio announcer's voice during the last ten years resulted in the creation of rather efficient recognition systems. The improvement and evolution of these systems are going on [15, 17]. There are different approaches to the practical realization of recognition systems of an announcer's voice. However, till nowadays there is no precise enough physical model influencing the voice individual characteristics which are the main acoustic parameters of speech formation.

Since Helmholtz times, the father of speech formation acoustic theory, despite a great number of researches the evolution of speech formation physical concepts hasn't been essential. The appearance of modern computer systems for speech formation researches allowed performing the practical task to recognize speech and identify the voice. However, there is no generally – recognized physical concept of voice individual characteristic formation.

One of the reasons of the concept lack is a great variety of different parameters and factors which are necessary to be considered while researching the voice characteristics [1, 2, 3]. Setting a further developed task, on the one hand allows creating the structural model of speech fragments which gives a full rational description of all main speech formation tasks. On the other hand, this model enables to increase sufficiently the research process of different factors influencing the individual characteristics of announcer's voice.

Any systems and models in the field of speech recognition [8, 18] must use a certain "modes" in generalized sense to recognize "atomic" speech components. Stored modes of words, sentences, phonemes and so forth in the form of sound fragments can be speech components. Just the parameters of mathematical models taking into consideration the pre-history of the process of sound wave alteration into audio file which are compared with some analogue mode-parameters can be speech components too. It is senselessly even to set a task of speech recognition without "modes" in generalized sense solving the task of recognition including modeling on the basis of neuron nets.

The question is arising. Is it possible to design modes which are the result of physical objects describing the definite "atomic" structure with quite definite invariant parameters?

The models of multi-fractal structure of speech sounds and the description of voice characteristics on the basis of these structures have been developed. The results of this development are presented in the paper.

## SETTING A TASK FOR THE RESEARCH

Let's consider the task of an announcer's voice recognition within the framework of the context-independent speech with unlimited language vocabulary and voluntary voice characteristics. Designing the main physical concept we shall consider the task at the level of phonemic components of the Russian language speech or the structures equivalent to phonemic components. This research deals not only with vowels of the Russian language -[a], [i], [o], [u], and [je]. Vowel phonemes are considered according to the provisions of Moscow phonological school. As it will be seen further this limitation is not important for the analysis of basic voice individual characteristics [5, 7, 14].

Let's consider the speech fragment in the form of sound wave chart – Figure 1 (here and further programmed complex "Fraktal" is used for charts and drawings design [10]).



Fig. 1. Speech fragment

The chart view depends on individual characteristics of voice, speech rate, and a number of other factors. The conformity between vowel phoneme of speech fragment and temporary intervals of a sound wave by means of listening to the fragments is set.

The criteria of developed model conformity with objectively existing voice characteristics are the basis of further research and the results of the development. The following research methodic is the basis of methodical solution of this problem.

During the listening the fragments of sound wave equivalent to vowels of the Russian language sounds are purposefully modified according to the developed physical model (in time and frequency fields). After modification these fragments are listened to by a group of tested people with the aim to reveal identity both phonemic sound of the first fragment and modified one, and the voice individual characteristics. The identification of phoneme sounding and voice characteristics before and after modification is determined in the case of 95% of recognition by the group of tested people. This methodic has definite limitations and a certain share of subjectivism. But nowadays man's organs of hearing is practically the only "standard device" which can be used.

The researches have been done both with separate pronounced vowel sounds and with sounds within the framework of different texts and voices characteristics.

The research results with a following set task are given. This set task includes: to reveal stable structures with definite parameters which completely characterize the definite phoneme, voice individual characteristics and they are context independent.

## MULTI-FRACTALS, VOWEL PHONEMS AND INDIVIDUAL CHARACTERISTICS

Speech fragments in audio-data as a discrete time row of sound wave amplitude are considered in the researches. It is necessary to reveal the self-similar structures in speech fragment of time row on the basis of which it is possible to form phonemes and voice

characteristics. Self-similarity is considered as self-similarity of multi-fractal structures in accordance with Mandelbrot's concept [9, 11, 12]. It is an approximate geometrical analogue, visually watched sound wave fragments. The fragment of sound wave of equivalent phoneme [i] (a part of phoneme fragment) is presented in Fig. 2.



Fig. 2. Fragment of acoustic wave (phoneme [i])

At the bottom of Fig. 2 there is Furrier's spectrum of excreted phoneme fragment. The spectrums of separately excreted definite vowels have some geometrical similarity between them. This approximate similarity is watched while seeing visually; it doesn't depend on the voice characteristics and the nature of phoneme pronunciation. A great number of works dealing with the finding of conformity between a spectrum and particular vowel phoneme indicate at a definite degree of interconnection. However an exact enough scientific grounded model to reveal conformity between vowel phonemes and spectrums doesn't exist.

Let's examine the similarity of amplitude fragments of sound wave phoneme [i] during small time intervals (approximately 5-20 ms) Fig.3.

Periodically repeating self-similar structures are watched in the time field of sound wave. (Fig.3). Fragment Furrier's spectrum during small time intervals is a little bit different from the spectrum on fig. 2 due to the position of local extremes in a frequency field as well as due to the extremes amplitude.

The phoneme fragment in the field of T=0.015-0.02 s. – fig. 4 singled out.



Fig. 3. Fragment of acoustic wave (phoneme [i])



Fig. 4. Phoneme fragment [i]

The spectrum of given small fragment is essentially different from the spectrums with large time intervals for the phoneme [i]. It also differs in frequency resolution due to the shortage of time intervals. The task of phoneme [i] "designing" from a small "atomic" phoneme fragment by means of affix transformations of widening and shortening is considered. From fragment given on fig.4 the acoustic fragment consisting of several tens completely similar fragments different from each other in an amplitude strain-grasp is designed. Fig. 5



**Fig. 5.** Fragment of modified amplitude of sound wave (phoneme [i])

Listening to a modified fragment the tested people have to identify clearly the phoneme [i]. The voice characteristics and time periods of "atomic" structure (from 5 till 15ms) varied during the experiment. The length of designed phoneme sounding has been changing in a wide range. Artificially designed phoneme [i] is quite clearly identified after transformations during the listening. Thus individual characteristics of initial voice are either absent or expressed very weakly.

Received results indirectly appear in many researches. However these results are only initial preconditions to design models of a multi-fractal structure of speech sounds and voice individual characteristics in this work.

Thus, fragments given above as research results show that vowel [i] can be presented ("designed") on the basis of definite "atomic" fragments of the same phoneme by means of a number of affix strain-grasp transformations by the "atomic" fragment amplitude.

Completely the same experiments for "a" phoneme also show the possibility to design this phoneme from "atomic" fragment with the phoneme size from 5 till 15 ms. Vowel phoneme of the Russian language – [o], [u], [je], as researches show have also a multi-fractal structure. These phonemes can be designed from "atomic" fragments of every phoneme.

At the same time it is necessary to note that in a number of cases not only one atomic structure is required to "design" the phoneme. The results of such researches are not the subject of this paper. They will be presented in other publications.

## THE DESIGNING OF VOWEL PHONEMES WITH VOICE INDIVIDUAL CHARACTERISTICS ON THE BASIS OF MULTI-FRACTAL STRUCTURES

Properly from the second section the Russian language vowel phoneme characteristics can be studied and determined by characteristics of "atomic" multi-fractal components. However individual characteristics of initial voice are disappeared in the majority of voluntary variations of the phoneme designing. The task to "design" vowel phoneme from multi-fractal components saving voice individual characteristics is examined.

Voice individual characteristics for vowel phoneme studying the modification of sound wave fragments both in a time field and in a frequency one are investigated. Firstly, today it is connected with famous neurophysical regularities of sound information processing by a man [4, 6, 13].

As a result of these researches which are given in section 2 it is necessary to note that sounding characteristics of "designed" phoneme depend on the sizes of "atomic" structures as well as on the structural phoneme geometry during visual examination in a time field. This fact is obvious. But individual characteristics of initial voice at such modeling are completely absent. It is only possible to identify man and woman's voices.

Let's examine the task of more complex affix transformations of "atomic" structures which take into consideration a number of important speech fragments.

Examine the phoneme fragment [i] on a small time scales – Fig. 6



Fig. 6. [i] Phoneme fragment

It is possible to design the phoneme [i] from any chosen "atomic" phoneme fragment within the interval of 5-15 ms on the basis of multi-fractal model given in section 2. However individual characteristics of initial voice are disappearing. We shall "design" atomic structure at time interval equivalent to the frequency of primary tone for the phoneme, Fig. 6. Here we shall examine two basic "atomic" structures for a given phoneme. One structure is with 0.019-0.024 Ms time interval. Another one is with 0.031-0.036 Ms interval.

Phoneme [i] is designed from two consecutive components on the basis of affix strain-grasp transformations. The first phoneme part is on the basis of the first atomic structure, the second part is on the basis of the second atomic structure. The share of each atomic structure in a designed phoneme is proportionally to corresponding time intervals, Fig.6. Received multi-fractal design is presented in Fig. 7.



Fig. 7. Phoneme [i] fragment designed of atomic structures

Listening to "designed" phonemes tested people must identify the characteristics of nonmodified voice. While perceiving there are still some differences of voice characteristics after modification.

Greater voice characteristics identity can be achieved while listening. It is possible to divide the phoneme into three or four basic "atomic" structures. However in this case it is more difficult to use the developed model in practice.

Thus, given research results show that it is possible to present vowel phonemes of the Russian language in the form of multi-fractal structures. Here the construction of vowel phoneme on the basis of multi-fractal approach permits to design voice individual characteristics.

#### CONCLUSIONS

1. Experimental researches dealing with frequency – time modification of vowel phoneme of the Russian language have shown

obviously vividly-expressed multi-fractal structure of vowel phonemes.

2. The multi-fractal structure of vowel phonemes is revealed that it is possible to "design" vowel phonemes from "atomic" phoneme fragments by means of affix transformations.

3. All these elements of voice model make possible to design voice individual characteristics on the basis of a multi-fractal structure of the Russian language phonemes.

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## МУЛЬТИФРАКТАЛЬНЫЙ ПОДХОД В ЗАДАЧАХ РАСПОЗНАВАНИЯ ГОЛОСА ДИКТОРА

#### Виктор Соловьев, Яна Белозерова

Аннотация. В статье приведены результаты исследований по выявлению мультифрактальных структур для гласных фонем. Показана возможность "конструирования" гласных фонем из "атомарных" структур фонем путем аффинных преобразований. Рассмотрены условия мультифрактальности, которые позволяют моделировать индивидуальные характеристики голоса.

Ключевые слова: самоподобные структуры, фрагменты речи, распознавание голоса, "атомарные" составляющие фрагментов фонем, фонемы, мультифракталы.

# Effect of expansive agent and shrinkage reducing admixture in shrinkage-compensating concrete under hot-dry curing environment

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S u m m a r y. The paper is devoted to the investigation of the influence of multifunctional modifier in the form of superplasticizer, shrinkage reducing admixture, CaO-MgO-based expansive admixture, and the agent of internal curing (pre-wetted lightweight aggregate as partial replacement of normal weight aggregate) on the properties of concrete mixtures and concrete exposed during 21 days of hardening under hot-dry curing environment. The combined addition of shrinkagereducing admixture with CaO-MgO-based expansive agent has been found to be successful in producing restrained expansion of concrete.

K e y w o r d s. Expansive agent, Internal curing agent, Shrinkage reducing admixture, Restrained shrinkage, Restrained expansion

## INTRODUCTION

The climatic conditions in the hot and arid areas of the world are considered to be very aggressive for concrete. The climatic factors in these regions (Pakistan, Iraq, Saudi Arabia etc) are typically manifested by large fluctuations in the daily and seasonal temperature and humidity. The temperature can vary by as much as 30°C during a typical summer day, and the relative humidity ranges between 40 and 100 % over a period of 24 h

[1-3, 8]. These sudden and continuous variations in temperature and humidity encountered in fresh concrete include: increased water demand, increased rate of slump loss, increased concrete temperature, shortened setting times, and possible increased plastic shrinkage. Issues encountered in hardened concrete are: lower strength, increased potential for uncontrolled cracking due to autogenous and drying shrinkage, and decreased durability [16, 18, 24, 29]. An accelerated slump loss and shorter setting times are, of course, undesirable because they reduce the length of time during which fresh concrete remains workable and can be handled properly and thoroughly compacted at the building site. In fact, the accelerated slump loss constitutes one of the major problems of hot weather concreting [29].

## **RESEARCH ANALYSIS**

The problems of Portland cement concrete in the hot and arid areas of the world has directed the attention of concrete technologists to search for concrete admixtures

to improve the quality of concrete to cope with the aggressive exposure conditions [3, 25, 26]. There are some means that may be employed in order to overcome the practical problems associated with the accelerated slump loss, and, in this respect, the possible use of chemical and mineral admixtures. It is well known, that the use of retarding admixtures, by slowing down the rate of hydration, would slow down the rate of slump loss and thereby the accelerating effect counteract of temperature.

It was found [29] that utilization of class F fly ash for replacing part of Portland cement, or part of the fine sand, can reduce the rate of slump loss in prolonged mixed concrete. So, it was concluded that under hot weather conditions the combined use of class F fly ash and retarders is to be recommended. On the other hand, it must be realized, however, that combined use of retarders and fly ash in concrete under hot weather conditions involves greater plastic shrinkage, and the vulnerability of the concrete to plastic shrinkage cracking is therefore increased. Hence, when fly ash is used, extra care should be taken in order to prevent such cracking by protecting the fresh concrete from drying as soon as possible after being placed and finished [29].

Shrinkage is an unavoidable property of concrete that can lead to cracking, thereby the serviceability of concrete limiting structures. though shrinkage be can minimized. The magnitude of the shrinkage the concrete composition, depends on especially the content and properties of the cement, and the water/cementitious materials ratio (w/cm), as well as the environmental conditions [7]. Shrinkage cracking can be a critical problem in concrete construction, for example, for flat-slab structures such as highway pavements, industrial slab-on-grade, for parking garages, and bridge decks, especially under hot weather conditions [9].

One way to reduce the shrinkage cracking is to provide chemical admixtures such as shrinkage-reduce admixtures (SRAs). These admixtures are generally organic polymers that reduce the surface tension of water. When SRAs are dispersed or dissolved in water used for concrete, the capillary stresses within the pore structure of drying concrete are lower, leading to a decrease in shrinkage deformations [14, 15, 21, 28].

During setting, a reduction in the maximum internal temperature and decreased rate of heat evolution was observed due to the presence of the SRA. This was attributed to a possible retardation of the setting produced by the incorporation of the SRA [9]. The implications of this behavior are that lower temperatures will occur in concretes with SRA leading to lesser contraction (i.e. thermal shrinkage) when the internal temperature reaches equilibrium with the environment [23].

Shrinkage compensating cements and expansion producing calcium sulfoaluminate based admixtures were used to offset volume changes from shrinkage and settlement in a number of applications. The formation of ettringite as the major source of expansion is commonly used in modern concrete to compensate the shrinkage [22]. In many instances, however, shrinkage compensating cements (types K, M and S) did not produce expansion necessary to maintain the dimensional stability. In hot, arid climates, higher expansion levels than those provided by shrinkage compensating cements were required to offset the adverse effects of drying shrinkage [27]. Besides, the reaction of ettringite formation begins immediately as soon as water has been added to the mix but it takes at least 3 to 7 days to be completed. Hence, since the formation of ettringite requires a large amount of water, continuous wet curing for about one week is required to achieve the potential planned expansion. Any deficiencies in the method of curing can reduce the amount of initial expansion that is needed to offset later drying shrinkage [31, 32].

Besides, the use of expansion potential generated by the ettringite formation, another important type of shrinkage-compensating admixture takes use of the hydroxide formation, e.g.  $Ca(OH)_2$  (Portlandite) and  $Mg(OH)_2$  [10]. In order to be successfully used as expansive agent, CaO and MgO must be

cooked at higher temperatures than 1000°C resulting in "dead burnt lime" or "dead burnt periclase". The CaO based concrete achieves the complete expansion in less than 3 days whereas it continues for at least 7 days in the case of sulpho-aluminate based concrete. So, CaO based shrinkage-compensating concretes require a shorter period of wet curing (about 2 days) in order to achieve the final planned expansion. For this reason, their performances in terms of expansion are less affected by deficiencies of curing and there is a lower risk of the presence of residual un-reacted CaO in concrete which could cause later expansion [11, 32].

Furthermore, a synergistic effect in the combined use of SRA and a CaO-based expensive agent in terms of more effective expansion in the absence of wet curing and lower shrinkage was reported [11]. On the other hand, the quick expansion induced by CaO obliges to use a rapid hardening concrete in order to better exploit the expansive reaction. Actually, the use of high strength cement class and superplasticizers to reduce w/c can increase the restrained expansion at the same CaO amount [32].

According to [31] as a result of inadequate initial expansion the drying shrinkage of Self Compacting Concrete (SCC) exposed during 30 days in air environment with a relative humidity of 65 % was  $\varepsilon$ =-100 µm/m. Besides, it's also due to the fact that the expansion of concrete at an early age, usually within 2-7 days, doesn't compensate the shrinkage that occurs at a later period of concrete hardening [19]. These problems can be avoided by using dolomite as raw material burnt at temperatures within 800-1200°C to produce CaO- and MgO-based expansive agent [19, 20, 33].

As for our mind, despite the type of shrinkage-compensating admixture used, it is necessary to mentioned that the expansion of concrete is strongly influenced by the w/cm ratio in concrete and the curing conditions. Thus, a prerequisite for obtaining High-Performance Concrete with compensated shrinkage is to use a set of chemical and mineral modifiers, including: - high range water reducing admixture (HRWRA) – to provide high strength of concrete,

- shrinkage reducing admixture (SRA) – to decrease the extent of long-term deformation in concrete as well as the maximum internal temperature and a rate of heat evolution,

- expansive admixture based on calcium and magnesium oxides obtained by calcination of dolomite,

- agent of internal curing (pre-soaked fine lightweight aggregate) – to reduce autogenous shrinkage cracking and to provide complete hydration of expansive admixture (magnesium oxide) at a later period of concrete hardening.

## MATERIALS AND METHODS

Ordinary Portland cement CEM I 42.5 N (OPC) which conforms to (EN 197 CEM I) and class F fly ash (FA) were used as cementitious materials. The chemical composition and physical properties of cementitious materials are given in Table 1.

**Table 1.** Chemical composition and properties of the materials used

Composition (%)	OPC	FA
Properties		
SiO <sub>2</sub>	21.4	53.6
$Al_2O_3$	5.8	21.8
$Fe_2O_3$	3.4	15.4
CaO	61.5	2.5
MgO	1.7	1.0
K <sub>2</sub> O+Na <sub>2</sub> O	0.7	2.8
$SO_3$	2.5	0.35
Loss on ignition	1.2	2.6
Bulk density (kg·m <sup>-3</sup> )	1310	950
Fineness (m <sup>2</sup> ·kg <sup>-1</sup> )	365 (Blaine)	305 (Blaine)

Two types of chemical admixtures were used in the study: a polypropylene glycol based SRA (Mapecure SRA-25, Mapei) and modified polycarboxylic ether superplasticizer (HRWRA) (Melflux 5581 F, BASF).

Dolomite  $(CaMg(CO_3)_2)$  with the chemical composition in oxide by weight percent CaO 34.5 wt.%, MgO 19.6 wt.% and loss on ignition 43.9 % used in this research to obtain the expansive admixture based on

calcium and magnesium oxides (calcination temperature is 1150°C during 1.5 hour). Besides, the expansive admixture Expancrete, Mapei (on the base of CaO oxide) was used for reference formulation of concrete mixture.

Crushed granite stone with a maximum nominal size of 10 mm and a specific gravity (dry) of 2.68. was used as aggregate with composition (mass-related percentage of the grain mix): 0...0.315 mm - 8%, 0.315...1.25 mm - 32%, 1.25...2.5 mm - 10%, 2.5...5.0 mm - 20%, 5.0...10.0 mm - 30%. The aggregate was washed and left to be air dried to saturated surface dry condition before being used.

Normal weight aggregate (NWA) was replaced partly by the lightweight aggregate (LWA) (rotary kiln expanded clay) with size fractions of 2.5-5 mm and a specific gravity (dry) of 1.25. The LWA was measured to have 24 h water absorption of 22.5 % by dry mass.

Proportioning mixtures for internal curing Internal curing (IC) of concrete is achieved by using a pre-wetted fine lightweight aggregate to provide the internal curing water. To proportion the internally cured mixtures a methodology is used that is based on a procedure developed by Bentz and Snyder [4-6], in which the amount of LWA is calculated based on the chemical shrinkage occurring in the sample. Equation 1 permits the calculation of the amount of LWA based on this theory [13]:

$$M_{LWA} = \frac{C_f \cdot CS \cdot \alpha_{max}}{S \cdot W_{LWA}}, \qquad (1)$$

where:  $M_{LWA}$  (kg/m<sup>3</sup>) is the mass of LWA (in a dry state) that needs to be prewetted to provide water to fill in the voids created by chemical shrinkage,

 $C_f$  (kg/m<sup>3</sup>) is the binder content of the mixture, *CS* (mL of water per g of binder) is the chemical shrinkage of the binder,

 $\alpha_{max}$  (unitless) is the expected maximum degree of hydration (0 to 1), S (unitless) is the expected degree of saturation of the LWA and

was taken to be 1 in this study when the dry LWA was soaked for 24 h,

and  $W_{LWA}$  (kg of water / kg of dry LWA) is the absorption capacity of the LWA (taken here as the 24 h absorption value).

two of the concrete mixture In formulations (C and D), corresponding to w/cm of 0.32 and cementitious materials (Portland cement + fly ash) content of 545  $kg/m^3$ , a portion of the normal weight aggregate was replaced with pre-wetted LWA. It is important to note that the volume of aggregate (NWA and LWA) remains constant at 61.4 %, since only a portion of the crushed granite was replaced with an equal volume of LWA. The replacement level for the LWA mixtures corresponds to the amount of LWA necessary to supply sufficient IC water to eliminate self-desiccation according to Eq. (1), with CS = 0.064 mL water/g binder and  $\alpha_{max} =$ (w/cm)/0.36 = 0.89. The volume of concrete occupied by the LWA corresponds to 11.2 %.

The proportions of the concrete mixtures are summarized in Table 2. To determine the effect of SRA on the properties of Self-Compacting Concrete in fresh and hardened state the concrete formulations with different content of admixture (A is the basic formulation) were prepared (A-0: 5.0, A-1: 5.5, A-2: 6.0, A-3: 6.5  $l/m^3$ ). The properties of mixtures concrete concrete and are summarized in Table 3. All the concrete mixtures were mixed for 5 min in a laboratory mixer.

Table 2. Mixture design and codes of the concretes

Material (lea/m <sup>3</sup> )	Code of the concrete						
Material (kg/III)	Α	В	С	D			
OPC	455	455	455	455			
Normal weight	166	163	133	133			
aggregate	0	0	5	5			
Dry lightweight aggregate	0	0	138	138			
Fly ash	90	90	90	90			
CaO-MgO expanding agent	0	36	36	0			
CaO expanding agent	0	0	0	36			
Dry superplasticizer	4.0	4.0	4.0	4.0			
SRA $(l/m^3)$	5.0	5.0	5.0	5.0			
w/cm	0.32	0.32	0.32	0.32			

Ма	Flowability		Viscosity		L-box,	Compressive strength, MPa			
JNG	SF, mm	Class	T <sub>500</sub> , s	Class	$H_2/H_1$	R <sub>7</sub>	R <sub>28</sub>	R <sub>56</sub>	R <sub>90</sub>
A-0	575	SF1	3.5	VS2/VF2	0.81	35.4	44.8	49.2	54.6
A-1	598	SF1	3.0	VS2/VF2	0.83	32.6	43.3	48.7	54.1
A-2	633	SF1	2.0	VS1/VF1	0.84	30.3	39.4	47.3	53.2
A-3	664	SF2	1.8	VS1/VF1	0.86	28.5	37.8	46.6	51.3

Table 3. The properties of fresh concrete mixtures and hardened concrete

The LWA was oven dried, air cooled, and then submerged in water for 24 h  $\pm$  1 h prior to mixing. The LWA was submerged in the total volume of water that included the mixing water needed for cement hydration and the water that would be absorbed by the LWA itself in 24 h.

The technological properties of SCC were determined in accordance with the European Guidelines for Self Compacting Concrete [30] (Fig. 1).



**Fig. 1.** Slump-flow test and  $T_{500}$  time (a) and passing ability (L-box test) (b) measurements of SCC

Cubes  $50 \times 50 \times 50$  mm were used to evaluate the compressive strength of concrete.

Tests are conducted at different test ages: 7-28-56-90 days of age. All experiments were performed on three specimen replicates. The average values are used in the discussion of the test results. All specimens remained in a humidity chamber (90 % < RH < 95 %) until the time of testing, at 28 days.

Restrained expansion and shrinkage of Shrinkage-Compensating Concrete was measured in accordance with ASTM C 878/C 878M-09. Molds for casting test specimens when used in conjunction with the restraining cage provide for forming prisms 50 mm square with a gage length of 250 mm. Restraining cage, consisting of a threaded low-carbon steel rod (zinc-coated) with steel end plates held in place by hex nuts as shown in Fig. 2.



Fig. 2. Mold with restraining cage

Concrete mixture was placed in the mold in two approximately equal layers (the first layer just covered the threaded restraining rod), each layer was consolidated by rodding. After consolidation was completed the specimens were covered with a polyethylene sheet to prevent loss of moisture at the surface of the specimens. The specimens were removed from the molds at the age of 10 h. After the initial comparator reading, the specimens were cured in lime-saturated water at  $20\pm2^{\circ}$ C until they had reached an age of 7 days. Every day and at the end of the curing period another comparator readings were taken. Further, samples were removed from water, put on substrates for subsequent exposure to 28 days in air at a relative humidity 45-55 % under ambient temperature  $+25...+32^{\circ}$ C (dry hot conditions). Every 2 days and at the end of the curing period comparator readings were taken.

## **RESULTS, DISCUSSION**

The influence of SRA on the technological properties of concrete mixtures and compressive strength

It was determined that in accordance with the European Guidelines for Self Compacting Concrete [30] all tested concrete formulations (A-0 – A-3) in terms of the ability to flow through the reinforcement bars without segregation or blocking (passing ability: L-box test H<sub>2</sub>/H<sub>1</sub>) can be assigned to class PA2 (Table 3). The higher dosage of shrinkage reducing admixture the higher was the flowability of fresh mixtures (slump flow) – classes SF1 (formulations A-0, A-1, A-2), SF2 (A-3) and the lower was viscosity (T<sub>500</sub>, s) – classes VS2/VF2 (formulations A-0, A-1), VS1/VF1 (formulations A-2, A-3).

One important effect of the incorporation of the SRA is the reduction in the early (7 day) and design (28 day) compressive strength of concrete. However the reduction in strength can be compensated by the use of a lower water/cementitious materials ratio, without compromising the workability, because as mentioned above SRA slightly improves the technological properties of fresh concrete mixtures. In more recent period of hardening concrete admixture influence on the compressive strength is significantly reduced.

It should be noted that the mechanism of SRA effect on concrete strength in literature remains debatable. Several authors showed that in contrast to the superplasticizers shrinkage reducing admixtures as nonionic polymer hardly adsorb on the surface of cement hydration products. Reduction in concrete strength is possible due to decreasing the degree of hydration of the Portland cement because SRA increases the surface area of hydrated products and accordingly the amount of physically bound water. As a result, there is not enough free water available for cement hydration in concretes with a low watercement ratio [14]. In this regard, by analogy with the problem of cracking caused by autogenous shrinkage in high-strength cement concrete with a low w/cm ratio, the problem of eliminating the retarding influence of SRA on the degree of cement hydration may be associated with the need for internal curing of concrete.

The influence of SRA, expansive admixture and internal curing agent on the restrained expansion and shrinkage of concrete

The results obtained can be observed in Fig. 3. As expected, all concrete samples revealed a tendency to expand during hardening in water for seven days. The higher values of restrained expansion observed for samples with expansive admixture on the base of burnt dolomite.

Shrinkage reducing admixture used in formulation A provides concrete exposed in dry, hot environment during 21 days with negligible restrained shrinkage.



**Fig. 3.** The influence of SRA, expansive admixture and internal curing agent on the length change behavior of a shrinkage-compensating concrete

The combined addition of shrinkagereducing admixture with a CaO-MgO-based expansive agent (concrete formulation *B*) has been found to be successful in producing restrained expansion of laboratory specimens immersed in water first seven days. However, when the samples were then placed in a hot, dry conditions the expansion of concrete decreased sharply. Eventually after 28 days the value of restrained shrinkage of concrete reached  $\varepsilon = -15 \ \mu m/m$ .

IC through the use of pre-wetted LWA was also investigated using two of the concretes (C and D). The agent of internal curing provides the value of residual restrained expansion of concrete samples placed in a hot, dry conditions during 21 days  $\varepsilon = +115 \ \mu m/m$ and  $\varepsilon = +60 \ \mu m/m$  for formulations *C* and *D* respectively. A higher absolute value of the restrained expansion of concrete containing CaO-MgO-based expansive agent (C)compared with concrete with the addition of Expancrete (Mapei) (D) is due, probably, the of magnesium presence oxide, which hydration occurs at a later period than calcium oxide.

It should be noted also that if pre-wetted agent of internal curing is added without changing the w/cm, a slight strength development is observed. The compressive strength of the concrete at the age of 28 days was 45.8 MPa (formulation B), 49.4 and 48.8 MPa (formulations C and D respectively). While all of the cement with the w/cm > 0.42should theoretically be able to fully hydrate, there would be a some fraction of unhydrated cement remaining in the system with w/cm of 0.32 to water limitations according to Powers' Model [17]. So, internal curing with prewetted LWA provides the higher degree of hydration in cement systems with low value of w/cm.

## CONCLUSIONS

1. It was established that polypropylene glycol SRA reduces the early (7 day) and design (28 day) compressive strength of concrete. However the reduction in strength can be compensated by the use of a lower water/cementitious materials ratio, without compromising the workability, because SRA slightly improves the technological properties of fresh concrete mixtures.

2. Shrinkage reducing admixture provides concrete exposed in dry, hot environment during 21 days with negligible restrained shrinkage.

3. The partial replacement of NWA with equivalent volume amount of pre-wetted porous aggregate (expanded clay sand) reduces shrinkage of concrete without a decrease in the strength properties of concrete due to the presence of additional water in the pores of LWA for more complete hydration of cementitious materials.

4. The agent of internal curing provides the value of residual restrained expansion of concrete samples placed in a hot, dry conditions during 21 days  $\varepsilon = +115 \ \mu\text{m/m}$  and  $\varepsilon = +60 \ \mu\text{m/m}$  for formulations *C* and *D* respectively. A higher absolute value of the restrained expansion of concrete containing CaO-MgO-based expansive agent compared with concrete with the addition of Expancrete (Mapei) is due, probably, the presence of magnesium oxide, which hydration occurs at a later period than calcium oxide.

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#### ВЛИЯНИЕ РАСШИРЯЮЩЕГОСЯ АГЕНТА И ДОБАВКИ, СНИЖАЮЩЕЙ УСАДКУ, В БЕТОНЕ С КОМПЕНСИРОВАННОЙ УСАДКОЙ, ТВЕРДЕЮЩЕГО В СУХИХ ЖАРКИХ УСЛОВИЯХ

#### Николай Зайченко, Антонина Назарова, Ал-Маршди Косай

Аннотация. Работа посвящена исследованию влияния полифункционального модификатора в виде суперпластификатора, добавки, снижающей усадку, расширяющейся добавки на основе оксидов агента CaO-MgO внутреннего ухода и водонасыщенный (предварительно пористый заполнитель в качестве частичной замены плотного заполнителя) на свойства бетонных смесей и бетона, твердеющего в течение 21 суток в жарких, сухих окружающей среды. Отмечено условиях положительное влияние комбинирования добавки, снижающей усадку и расширяющего агента на основе оксидов CaO-MgO на эффект стесненного расширения бетона.

Ключевые слова. Расширяющая добавка, агент внутреннего ухода, добавка, снижающая усадку, стесненная усадка, стесненное расширение ствие.

# Modelling of electromagnetic processes in ferromagnetic screens shorted winding asynchronous motor-fan with two rotor package using program complex FEMM 3.4

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S u m m a r y. Defined active and inductive resistances of the rotor winding through the simulation of electromagnetic processes in ferromagnetic screens shorted winding asynchronous motor-fan with two rotor package using program complex FEMM 3.4.

K e y w o r d s : asynchronous motor-fan, simulation of electromagnetic processes, ferromagnetic screens.

## INTRODUCTION

Locomotives operated on the possibility of using the effective power of the diesel engine for traction work is far from being full. So existing diesel locomotives directly transmitted to the wheels only (0.73-0.76) efficient diesel power. The rest of the power consumed by losses in electrical transmission, the drive mechanisms and auxiliary diesel engine cooling.

On diesel engines, cooling of diesel is carried out by a relay method by means of including and disconnecting of asynchronous motor-fans (AMF).

This part of the standard freight locomotive type 2TE116 capacity of 2200 kW per section for passenger locomotives TEP150 capacity of 3100 kW. When the relay cooling occur: temperature fluctuations coolants, heavy starting conditions motor-fans, a significant power consumption by fan drive to operate a diesel locomotive at ambient temperatures below +40°C and no nominal operating conditions of diesel. For the increase of economy of the system of cooling of diesel it is expedient to apply the continuous adjusting of frequency of rotation of fans [13, 14].

This is because the volume of air that is supplied by a motor-fan for cooling diesel depends on first power of the rotational speed and the shaft power of the fan depends on the third power of the speed.

General Electric Company in locomotives with index 8 (B23-8, B30-8, C30-8, B36-8, C36-8, etc.) replaces mechanical fan drives on two DC motor power 44 kW, speed of each run power semiconductor regulators function of water temperature at the outlet of the diesel engine. As a result, average operating power consumption by fan drive down 60%.

Company General Motors replaced in locomotives SD series three one speed AMF capacity of 29.6 kW diesel on two speed. Application of two-speed AMF compared with single-speed diesel locomotives series SD 2940 kW capacity gives fuel savings of 7.6 to 12.5 thousand liters per year.

Consequently, the development and introduction of more fuel-efficient locomotives for cooling systems for diesel engine with continuously adjustable electrically operated fan is very timely.

On new diesel engines for diminishing of expenses of energy on cooling of diesel the managed is offered the change of voltage on the winding of stator asynchronous motor-fan with a two package rotor with ferromagnetic screens in short-circuited winding of rotor. It promotes pure resistance of winding of rotor and provides good regulation descriptions.

An asynchronous motor-fan with a two package rotor (Fig. 1) contains stator 1 with a winding and stator core, connected with foundation 2 by a hob 3, which carries the supporting bearings 4. Shaft 5 connected with a rotor by a butt-end shield 6.

A rotor is executed a two package with two short-circuited winding for the increase of pure resistance of winding of rotor. One package of rotor is contained by bars 7 and 8, external rings 12 and internal rings 13. Rings 12 and 13 short-circuit short-circuited bars 7, 8. A rotor contains a wheel 9, on which blades are fastened 10. There are butt-end ferromagnetic screens 11 for rings 12 and 13. Screens engulf rings.

Between ferromagnetic screens 14 there а circular vent slot 15. Internal is ferromagnetic screens 14 cool down through openings 16 in foundation 2, through openings 17 in the lower package of stator 1, through the slots of explorers of winding stator between two packages of stator, through a circular slot 15 between internal screens 14, through openings 18 in a wheel 9. External ferromagnetic screens 11 cool down from blades 10.

Magnetic fields of dispersion of rings 12 and 13 winding of two package rotor induce eddy currents in the ferromagnetic screens of rings 11 and 14 and create additional losses in screens 11 and 14, that increases equivalent active resistance of rotor.

Ferromagnetic screens 11 cool down the current of air of blades 10. Ferromagnetic screens 14 cool down through vent openings 16, 17, 18 and circular slot 15. A thermal stream, that goes from a rotor to stator 1 with two by laminated packages, goes down, the winding of cratopa does not overheat. Due to it reliability of work of motor-fan rises in the wide turn-down of sliding.



Fig. 1. Construction of asynchronous motor-fan with the screened short-circuited rings in of rotor winding with a two package rotor
A two package rotor with two shortcircuited windings is needed for the additional increase of active resistance of rotor winding from additional internal short-circuited rings 13 with ferromagnetic screens 14 for motorfans with the number of poles more than 4.

Internal screens 14 can absent.

Voltage on stator diminish for adjusting of rotation speed of motor-fan. Rotation speed of motor-fan diminishes. Sliding of rotor is increased. Frequency of current is increased in the rotor winding. Frequency of eddy currents is increased in ferromagnetic screens 11. Additional losses are created in a rotor and active resistance of rotor is increased. Stiffness of mechanical characteristics is reduced. Stable operation of the motor-fan is provided in the range of variation of the slip from  $s=s_r$ to s=1.

Active and inductive resistances of rotor winding must be defined for the calculation of mechanical and regulation characteristics of motor-fan.

The method of calculation of active and inductive resistances of rotor winding is developed taking into account losses in ferromagnetic screens. Losses in ferromagnetic screens determined by solving the equations of the electromagnetic field in ferromagnetic elements winding (in screens) rotor.

Analytical methods for solving equations of the electromagnetic field in ferromagnetic elements of rotor windings differ generality and clarity of the solutions obtained. Particularly deep analytical methods developed for induction motors with solid rotors [8, 20, 9, 16] and two-layer rotors [12, 11, 15, 17, 3].

The analytical methods of calculation of the electromagnetic field in ferromagnetic bodies are based on the row of assumptions: 1) constancy of permeability of environment, 2) assumption of a sudden manifestation of the skin effect, 3) hyperbolic distributing of permeability on the depth of array, 4) account only by the tangential constituent of the magnetic field. These methods give acceptable integral characteristics of the field and parameters of massive ferromagnetic environment [2, 19].

Application of numeral methods considerably extends possibilities of research of processes in ferromagnetic elements, allows to take into account non-linearity of environment a task the known dependence B(H) [10].

To date, accurately enough electromagnetic field calculation possible using numerical methods, in particular, the finite element method (FEM). To calculate the two-dimensional fields of finite element method known the following: licensed version ELCUT [1] and the free version of FEMM 3.4 [4].

## OBJECT OF RESEARCH

A research object is distributing of the electromagnetic field in the ferromagnetic screens of rotor for determination of active and inductive resistances of rotor winding.

## PURPOSE OF RESEARCH

The purpose of this study is modelling of electromagnetic processes in ferromagnetic screens shorted winding of rotor asynchronous motor-fan with two package rotor using FEMM 3.4 software. On results the calculation of the magnetic field in a screen determine active and reactive powers in a screen for determination of active and inductive resistances of the rotor winding.

## **RESULTS OF RESEARCH**

For the calculation of descriptions of motor-fan it is necessary to define active and inductive resistances of rotor winding for one package. A rotor will present as a polyphase winding. The number of phases is equal to the number of bars of rotor winding. The number of pair of poles of rotor winding is equal to the number of pair of poles of stator winding.

Active  $r_2$  and inductive  $x_2$  resistances of rotor winding for one package are determined [21]:

$$r_2 = r_b + \frac{r_{rs}}{2\sin^2\frac{\pi p}{z_2}}, x_2 = x_b + \frac{x_{rs}}{2\sin^2\frac{\pi p}{z_2}}$$

where:  $r_b$  and  $x_b$  – active and inductive resistances of bar 7 (Fig. 1) determined ordinary a way [6],

 $r_{rs}$  and  $x_{rs}$  – active and inductive resistances of short-circuited ring 12 with a screen 11,

 $z_2$  – number of slots of rotor.

Will define active and inductive resistances of area of short-circuited ring of rotor winding between two bars with a ferromagnetic screen taking into account the skin effect by using complex software FEMM 3.4 [1, 4].

The geometrical sizes of screen followings: height h (on a co-ordinate y), thickness b (on a co-ordinate z). Middle diameter of ring  $D_{rs}$ , length  $l_r$  of ring (between two nearby bars of rotor, on a coordinate x):

$$l_r = \frac{\pi D_{rs}}{z_2} \,. \tag{1}$$

On a (Fig. 2) calculation chart is resulted for the real area of short-circuited ring with a ferromagnetic screen between two bars of rotor winding.



**Fig. 2.** Area of short-circuited ring with a ferromagnetic screen between the bars of rotor: 1 – ferromagnetic screen, 2 – short-circuited ring of rotor winding, 3 – laminated package of rotor,  $b_r$  and  $h_r$  – width and height of ring,  $l_r$  – length of area of ring between the bars of rotor winding, b – a thickness of ferromagnetic screen

Calculation of the magnetic field in the screen by the method of finite elements in axisymmetric formulation of the problem. (Fig. 3, a) shows the block diagram for the site shorting ring with a ferromagnetic screen between two bars of the rotor winding. The basic equation for the calculation of the magnetic field has the form [1, 6]:

$$\frac{\partial}{\partial r} \left( \frac{1}{r\mu_z} \frac{\partial (rA)}{\partial r} \right) + \frac{\partial}{\partial z} \left( \frac{1}{r\mu_r} \frac{\partial A}{\partial z} \right) - \frac{i\omega A}{\rho_r} = -j \qquad (2)$$

where: A – complex vectorial magnetic potential,

r, z – normal vectors on a radius and on an axis,

 $\rho_r$  – specific active resistance,

 $\mu_z, \mu_r$  – vectors of permeability,

 $\omega$  – angular frequency of the current,

j – external current density.





**Fig. 3.** Computational domain (a) and finite-element mesh (b) to calculate the magnetic field of short-circuited ring with a ferromagnetic screen

The followings assumptions are accepted:

1) the field in a screen is axisymmetric,

2) the external magnetic field of screen absents,

3) the currents of stator winding do not influence on the field of ring with a ferromagnetic screen,

4) the laminated core of rotor is unsaturated, therefore permeability is equal to endlessness,

5) material of screen is izotropic characteristics  $\mu_r = \mu_z = \mu_{rs}$ ,

6) ignore the phenomenon of hysteresis in a screen.

The followings scope terms are accepted:

1) on a border 1(Fig. 3, a) condition of Dirichlet on a border-vectorial magnetic potential is equal to the zero (A=0),

2) on a border 2 (Fig. 3, a) border condition of Neyman – the normal derivative of vectorial magnetic potential is equal to the zero  $\frac{\partial A}{\partial n} = 0$  [14].

For the calculation of the magnetic field the followings materials were chosen in obedience to the (Fig. 3, a): a screen is steel of St3, a ring is an aluminium alloy of AK12M4 with a current. The curve of dependence of H (B) is synonymous and determined dependence for steel of St3 [7]:

$$H = B\left(8,2 + \left(0,886|B|\right)^{8,6}\right).$$
 (3)

Computational grid with triangular finite elements of the first order is shown in (Fig. 3, b). Calculations of the magnetic field carried by a free version of the program FEMM 3.4.

On results the calculation of the magnetic field in a screen determine complete  $S_s$  power by FEMM 3.4, selected in a screen. Determine also active and reactive constituents of current in a screen, which the power-factor of screen is determined from, that allows to expect active  $P_s$  and reactive  $Q_s$  powers in a screen.

Currents in a short-circuited ring and ferromagnetic screens are different, therefore their active and inductive resistances at determination of general resistance of ring with a screen must be resulted to one current.

Calculation active resistance  $r_{rs}$  of shortcircuited ring of rotor winding with a screen for one package, determined on condition of equality of active powers, selected in resistance  $r_{rs}$  from a current  $I_r$  in the screened short-circuited ring and separately in a ring and in a ferromagnetic screen:

$$I_r^2 \cdot r_{rs} = I_r^2 \cdot r_r + P_s \,, \tag{4}$$

from where follows:

$$r_{rs} = r_r + \frac{P_s}{I_r^2} \quad , \tag{5}$$

where:  $r_r$  – active resistance of area of ring between nearby bars.

Calculation inductive resistance  $x_{rs}$  of short-circuited ring of rotor winding with a screen will get like (4) on equation:

$$I_r^2 \cdot x_{rs} = I_r^2 \cdot x_r + Q_s , \qquad (6)$$

$$x_{rs} = x_r + \frac{Q_s}{I^2},\tag{7}$$

where:  $x_r$  – inductive resistance of area of ring between nearby bars.

In the absence of the inductive reactance of the screen ring from external leakage flux is determined [4]:

$$x_{rse} = 9.1 \cdot f \cdot l_r \cdot 10^{-6} \cdot \lg \frac{4.7 \cdot l_r}{\pi [(h_r + 2b_s) + (b_r + b_s)]} \cdot (8)$$

Active resistance of area of ring from [21]:

$$r_r = r_{ro}\lambda_r \frac{(ch2\lambda_r + \cos 2\lambda_r)(sh2\lambda_r + \sin 2\lambda_r)}{sh^2 2\lambda_r + \sin^2 2\lambda_r}, \quad (9)$$

inductive resistance of area of short-circuited ring from [21].

$$x_r = r_{ro}\lambda_r \frac{(ch2\lambda_r + \cos 2\lambda_r)(sh2\lambda_r - \sin 2\lambda_r)}{sh^2 2\lambda_r + \sin^2 2\lambda_r}, \quad (10)$$

where:  $r_{ro}$  – resistance of area of ring to the direct current:

$$r_{ro} = \frac{\rho_r l_r}{b_r h_r} \,. \tag{11}$$

$$\lambda_r = \frac{b_r}{\Delta_r},\tag{12}$$

$$\Delta_r = \sqrt{\frac{2\rho_r}{\omega\mu_r}} , \qquad (13)$$

where:  $\Delta_r$  – depth of penetration of electromagnetic wave in the short-circuited ring of rotor winding.

Using on the software FEMM 3.4 in a table 1 and tabl2 2 active  $P_s$  and reactive  $Q_s$  powers of ferromagnetic screen are expected depending on frequency and value of current  $I_s$  in the screened short-circuited ring. The sizes of screen are resulted on a (Fig. 4).



**Fig. 4.** Construction of short-circuited ring of rotor winding with a ferromagnetic screen for AMF by power 75 kW with the number of poles 8:

- 1 ferromagnetic ring-screen from steel of St3,
- 2-short-circuited ring,
- 3 bar of rotor winding from an aluminium alloy,
- 4 lamineted package of rotor from steel 2411

According to the results of theoretical analysis of electromagnetic processes in AMF with two package rotor simulation algorithm developed motor-fan with two packet rotor for steady-state modes. Determined according to: speed *n* or slip *s*, consumption current  $I_1$ , efficiency  $\eta$ , power factor  $\cos \varphi$  on the value of the phase voltage  $U_{\rho h}$  on the stator winding. Parameters are calculated on a PC on the developed program in a language  $C^{++}$  that uses the results presented in (Table 1) and (Table 2).

Table 3 shows a comparison of calculated and experimental data for the motor-fan (nominal power of 75 kW) with the number of poles 2p = 8 on both the rotor and the packet with one screen on every package. When calculating the time of useful features for changing the fan wheel takes the square of the speed, which is slightly different from reality at low speeds.

From (Table 3) follows:

1) for nominal operation mode AMF error in determining consumption current does not exceed 3.9% slip -3.3% efficiency -0.59%,

2) by adjusting with the highest accuracy simulated sliding AMF -10%.

Current in a	Frequency of current in a ring, Hz								
ring, A	5	25	45	65	85	105			
200	0.32	0.72	0.96	1.12	1.32	1.44			
600	1.80	3.96	5.40	6.48	7.20	8.28			
1000	4.00	9.00	12.00	14.00	16.00	18.00			
1400	5.88	15.68	19.60	23.52	27.44	31.36			
1800	6.48	22.68	29.16	35.64	42.12	45.36			
2200	9.68	33.88	38.72	48.40	53.24	62.92			
2600	6.76	40.56	54.08	60.84	74.36	81.12			
3000	9.00	54.00	72.00	81.00	90.00	99.00			
3400	11.56	69.36	80.92	92.48	104.04	115.60			
3800	14.44	72.20	101.08	115.52	129.96	144.40			

Table 1. Results of calculation of active power  $P_s$  on the area of ferromagnetic screen (W) between the bars of rotor

Current in a	Frequency of current in a ring, Hz								
ring, A	5	25	45	65	85	105			
200	0.32	0.72	0.96	1.12	1.32	1.44			
600	2.16	3.96	5.40	6.48	7.20	8.28			
1000	5.00	9.00	12.00	14.00	16.00	18.00			
1400	9.80	13.72	19.60	23.52	27.44	31.36			
1800	12.96	22.68	29.16	35.64	42.12	45.36			
2200	19.36	29.04	38.72	48.40	53.24	62.92			
2600	20.28	40.56	54.08	60.84	74.36	81.12			
3000	27.00	54.00	63.00	81.00	90.00	99.00			
3400	34.68	69.36	80.92	92.48	104.04	115.60			
3800	43.32	86.64	101.08	115.52	129.96	144.40			

**Table 2.** Results of calculation of reactive power  $Q_s$  on the area of ferromagnetic screen (VAr) between the bars of rotor

Table 3. Comparative analysis of theoretical and experimental data AMF75-2P-8 at a frequency of 100 Hz\* voltage

Phase voltage, $U_{pf}$ , V	Phase curr Calculation	Tent, $I_1$ , A	Error, %	Slip,	s, %	Error, %	Efficienc	y, $\eta_{MB}$ , %	Error, %
230	173	180	-3.9	6.12	6.1	3.3	84.9	84.4	0.59
200	189	199	-5.0	9.29	9.8	-5.2	81.7	80.8	1.11
180	204	216	-5.6	14.1	15.7	-10.0	77.5	74.6	3.9
160	224	230	-2.6	23.0	25.3	-9.0	68.3	64.5	5.9
140	223	219	1.8	37.8	36.7	3.0	51.8	53.5	-3.2
120	193	194	-0.5	51.8	48.6	6.6	38.5	42.3	-8.9
100	158	159	-0.6	62.8	60.3	4.0	29.1	32.3	-9.8
80	120	122	-1.6	71.2	68.7	3.6	22.2	24.6	-9.6
64	98	100	-2.0	80.5	77.9	3.3	14.8	16.3	-9.4

\* Note. At rated speed 1405 r / min useful power AMF 73.4 kW.

Increased accuracy in determining the efficiency to 10% for large slides (at low speeds) can be attributed to some mismatch of real characteristics of the fan load torque resistance of the estimated quadratic.

The results of calculation of the magnetic field of the pictures in the ferromagnetic screen shown in (Fig. 5-8), which show that the magnetic field is concentrated mainly in the ferromagnetic screen, so the assumption holds no boundaries for its screen, namely in the air and a shorting ring. The figures also show that at higher sliding rotor, a more sharp manifestation of the skin effect in a ferromagnetic screen, and consequently an increase in resistance of the screen while reducing the speed by varying the voltage on the stator winding.

Fig. 9 shows the calculated dependence of consumption current  $I_1$  and the slip *s* of the supply voltage  $U_{ph}$  at  $f_1 = 100$  Hz for AMF 75 kW with different design of the rotor winding of aluminum alloy AK12M4: one package without ferromagnetic rotor screens, one package rotor with ferromagnetic screens, two package rotor with a locking ring screened in each package two rotor windings.



**Fig. 5.** Distribution power lines and the magnetic field in the ferromagnetic screen for motor-fan AMF75-2P-8 at a supply voltage of 230 V, 100 Hz and the rotor slip 6.1% (frequency current in the ring 6.1 Hz, the current in the ring 1324 A)



**Fig. 6.** Distribution of field lines and the magnetic field in the ferromagnetic screen for motor-fan AMF75-2P-8 at a supply voltage of 160 V, 100 Hz and rotor slip 23% (current frequency 23 Hz in the ring, the ring current 1888 A)



**Fig. 7.** Distribution of field lines and the magnetic field in the ferromagnetic screen for motor-fan AMF75-2P-8 at a supply voltage of 100 V, 100 Hz and the rotor slip 62.8% (current frequency of 62.8 Hz in the ring, the ring current 1331 A)



**Fig. 8.** Distribution of field lines and the magnetic field in the ferromagnetic screen for motor-fan AMF75-2P-8 at a supply voltage of 30 V, 100 Hz and rotor slip 93% (current frequency 93 Hz in the ring, the ring current is 245 A)



**Fig. 9.** Dependencies consumption current  $I_1$  (1-4) and the slip s (1'-4') of AMF from the supply phase voltage  $U_{ph}$ : 1, 1' – one package without ferromagnetic rotor screens, 2, 2' – one package with ferromagnetic rotor screens,

3, 3' – two package rotor without ferromagnetic screens,

4, 4' – with a rotor end ring screened in each package two rotor windings

Table 4 shows the calculated nominal data compared variants.

From (Fig. 9) and (Table 4) that AMF with one shielded locking ring in each winding rotor has two batch most favorable control characteristics  $s = f(U_{ph})$ , the maximum input current  $I_1$  exceeds the nominal 27%, but this option is AMF in nominal mode has reduced the efficiency values and  $\cos \varphi$ .

Fig. 10 shows the dependence of the active  $\bar{r}_{rs}$ , inductive  $\bar{x}_{rs}$  resistances shielded rings and the penetration depth of the electromagnetic wave (current)  $\Delta_s$  from sliding (speed control AMF voltage changes), which were determined by the dependences obtained in the (Eg. 5), (Eg. 7), (Eg. 9) with algorithm simulation according to Annexes A and program developed in C<sup>++</sup>.



Fig. 10. Dependencies relative parameters of the rotor slip (speed control AMF voltage change):

1 – active resistance 
$$\overline{r}_{rs} = \frac{r_{rs}}{r_{rsr}}$$
,  
2 – inductive reactance  $\overline{x}_{rs} = \frac{x_{rs}}{x_{rsr}}$ ,

3 – penetration depth of the electromagnetic wave shield  $\overline{\Delta} = \frac{\Delta_s}{b_s}$ 

Rotor parameters  $r_{rsr}$ ,  $x_{rsr}$  for the nominal mode, determined at  $U_{ph} = 230 V$  and sliding  $s_r = 0,061$ .

**Table 4.** Comparative analysis of nominal modes AMF with different design of the rotor at a frequency of 100 Hz and supply voltage 230 V

Variant of AMF	Current, $I_1$ , A	Slip, <i>s</i> ,%	Efficiency, $\eta$ , %	Power factor, $\cos \varphi$ , r.u.	Useful power, $P_2$ , kVA
One package of ferromagnetic rotor without screens	160	2.47	88.0	0.773	75.1
One package rotor with ferromagnetic screens	161	3.28	87.3	0.772	75.1
Two packages rotor without ferromagnetic screens	171	4.28	86.7	0.732	75.0
Rotor with a shielded locking ring in each package two rotor winding	173	6.12	84.9	0.727	73.4

### CONCLUSIONS

1. As follows from (Fig. 10) in deep regulation for large slides active and inductive resistances shielded rotor rings increase 3 times, and the depth of the current flow  $\Delta_s$  in the screen also significantly reduced due to the influence of the skin effect in a ferromagnetic screen.

2. Results shown in (Fig. 9), in the (Table 4) and in (Fig. 10), make it appropriate shielding rings rotor winding to improve the control characteristics of the asynchronous motor-fan when the voltage on the stator.

3. Comparative analysis of steady-state performance with different AMF rotor design identified (Fig. 9) that one package of motorfan designs without serial ferromagnetic screens largely unregulated, i.e, significantly increasing the slip from 20% to 55% when the total voltage from 140 V to 120 V. The current consumption is increased to 340 A, which is unacceptable. Motor- fan with a shielded locking ring in each winding rotor has two package adjusting most favorable properties: slip varies smoothly, the current exceeds the maximum current at rated voltage of not more than 27%.

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#### МОДЕЛИРОВАНИЕ ЭЛЕКТРОМАГНИТНЫХ ПРОЦЕССОВ В ФЕРРОМАГНИТНЫХ ЭКРАНАХ КОРОТКОЗАМКНУТОЙ ОБМОТКИ АСИНХРОННОГО МОТОР-ВЕНТИЛЯТОРА С ДВУХПАКЕТНЫМ РОТОРОМ С ПОМОЩЬЮ ПРОГРАММНОГО КОМПЛЕКСА FEMM 3.4

#### Игорь Захарчук

Аннотация. Определены активное и индуктивное сопротивления обмотки ротора путем моделирования электромагнитных процессов в ферромагнитных экранах короткозамкнутой обмотки асинхронного мотор-вентилятора с двухпакетным ротором с помощью программного комплекса FEMM 3.4.

Ключевые слова: асинхронный моторвентилятор, моделирование электромагнитных процессов, ферромагнитные экраны.

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