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Factor Analysis of the Technical Level of Single-Bucket Hydraulic Excavators

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***Abstract*— In article briefly outlines the technique of factor analysis on indicators of the world technical level of engineering products. On basic data it has only methodical character. Therefore the offered technique for practical purposes demands updating of the table of basic data. Theoretical and practical bases of a method of the full factorial analysis of parameters of machines on the example of functioning indicators of the single-bucket hydraulic excavators of various countries are stated. As of 70-80 years of the XX century the technique of an assessment of a world technological level is shown. Ratings of brands of excavators and their manufacturers are made. Statistical models of mutual influence of parameters of excavators are given and the technique of an assessment of their adequacy is shown. Correlation matrixes and the analysis of the strongest factorial communications with wave components are given.**

***Index Terms*—excavators, indicators, countries, manufacturers, regularities.**

I. INTRODUCTION

The period of doubling of volume of information is reduced, scientific and technical progress is accelerated. The machine is a part of «clothes» of the person, continuation of his extremities and its creation is accelerated. From such concept we offered methodology of the factorial analysis of indicators of any uniform group of technical devices. Excavators are unique population of devices: first, domestic (soviet) excavators were at the level of a world technological level; secondly, on them was publications according to the analysis of a technological level in comparison to world manufacturers enough. The general recommendations about an assessment of a technological level are provided in the document [4]. It was created in the consolidated department analysis of the scientific and technical level SCST USSR under the leadership of N.P. Laverov. Evaluation of the technical level consists of determining the conformity of manufactured products to the world, regional, national level or the level of the industry. However, a disadvantage of the proposed methodology was its focus only on a qualitative scale of assessment type: corresponds (C), is approaching to the world or other technical level (P), and inferior to the world or other technical level (U). Statistical models on technical characteristics [1-3] so far in the world is not detected.

II. SINGLE-BUCKET HYDRAULIC EXCAVATORS

High homogeneity in many countries and firms-manufacturers on the flows of matter, energy and information (signal) has a group of machines - single-bucket full-circle hydraulic excavators. Several types and sizes of groups were produced in the USSR. To select the best brands excavator need to analyze their technical data [2].

On functional-structural-parametric community selected ***functor excavators*** (table. 1).

In table 1 as adopted conventions: Γ - dimensional group on operating weight with a basic working equipment: 1 - up to 6,3 tons; 2 - from 6,3 up to 10 tons; 3 - from 10 to 18 tons; 4 - from 18 to 32 tons; 5 - from 32 to 50 tons; 6 - from 50 to 71 tons; T - type chassis: 1 - caterpillar; 2 - tracked with increased bearing surface, 3 - wheel; M - mass excavator operating with the main working equipment, tons; V - bucket capacity in reverse shovels, m^3; R - kinematic depth of digging, m; g - operating cycle of digging, sec ; q - the specific fuel consumption, g/m^3; $t_к$ - motor potential before capital repairs, h; t_{om} - time between failures, h, S - code groups of countries-manufacturers; I - place on a rating of manufacturers. Many excavators were selected by the homogeneity of the description of the list of indicators adopted of non-departmental commission for characteristics of structural appearance single-bucket full-circle hydraulic excavators (cards technical level and product quality). Of these cards accepted clusters of three excavators (valued products and two foreign analogue). These clusters are distinguished by two characteristics: size group Γ and type of suspension device T . From 25 excavators combinations of codes Γ and T formed six clusters included in the functor (functional many machines). Values of parameters M , V , R , g , q , $t_к$ and t_{om} adopted according to VNIIM. In total these indicators characterize also work on soil excavation. But many indicators incomplete. To improve the adequacy of modeling, you need to take more primary indicators. Derived indicators, for example, type "specific gravity", factor analysis are excluded.

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Table 1 - Technical data single-bucket hydraulic excavators [2]

№	Brand of the excavator, firm, country	$Г$	T	M, tons	V, m^3	R, m	g, sec	q, g/m^3	$t_к$, h	$t_{от}$, h	S
1	ЭО-3122	3	1	14.5	0.75	5.2	16.5	90	8200	180	2
2	75 CE «Poquelin», France	3	1	14.7	0.62	5.0	22.0	99	8200	170	3
3	PH-5 «Orenstein-Koppel», Germany	3	1	15.1	0.7	5.1	18.0	123.7	8200	170	3
4	ЭО-3221	3	2	14.0	0.57	5.76	17.0	98	8250	180	2
5	R 900 «Liebherr» Germany	3	2	15.9	0.6	6.2	20.0	100	8000	190	3
6	60 CK «Poquelin», France	3	2	12.68	0.48	5.65	22.0	99	8000	190	3
7	ЭО-3323	3	3	13.8	0.75	4.62	16.5	91	8380	190	2
8	75 PB «Poquelin», France	3	3	14.4	0.77	4.6	22.0	99	7860	170	3
9	MH-5 Germany	3	3	14.15	0.7	4.8	18.0	123.7	8200	170	3
10	ЭО-41121Б	4	1	22.8	1.1	6.0	19.0	103	9550	200	2
11	UH121 «Hitachi», Japan	4	1	26.0	1.0	6.5	24.0	117	10000	180	2
12	R 932 «Liebherr», Germany	4	1	24.4	1.1	6.5	24.0	117	9100	160	3
13	ЭО-4321Б «Liebherr», Germany	4	1	25.6	1.1	7.3	18.5	94	10000	220	2
14	YH 123 «Hitachi», Japan	4	1	26.0	1.0	7.2	24.0	100	10000	215	1
15	R 932 «Liebherr», Germany	4	1	24.4	1.1	6.5	24.0	117	9100	160	3
16	ЭО-4321Б	4	3	19.5	1.0	5.5	19.6	85	9150	170	2
17	A 932 «Liebherr», Germany	4	3	20.9	1.0	5.83	20.6	117	9100	170	3
18	224 «Caterpillar», USA	4	3	20.0	1.0	5.6	21.0	118	9100	170	3
19	ЭО-5124(1)	5	1	38.7	1.86	6.5	24.5	110	10500	180	2
20	ЭО-5124(2)	5	1	38.7	1.45	7.3	24.5	141	10500	180	2
21	220 CKB «Poquelin», France	5	1	42.3	1.7	7.5	26.5	195	10500	170	3
22	UH 181 «Hitachi», Japan	5	1	41.0	1.4	7.27	24.4	192	10000	180	1
23	ЭО-5124-2(1)	5	1	38.0	1.86	6.5	24.5	110	10500	180	2
24	ЭО-5124-2(2)	5	1	38.0	1.45	7.3	24.5	141	10500	180	3
25	2202E-НД «Atlas», Germany	5	1	40.8	1.5	7.4	26.0	170	10500	160	3

III. ACCOUNTING OF THE COUNTRIES MANUFACTURERS

For many excavators should also enter the code indicators of type "country", "firm" and "brand ". Ranking of firms within the same country will take a great many types of excavators. Therefore, the following is an approach to ranking of countries-manufacturers of excavators. Table 2 shows the calculation of arithmetic mean $t_к$ and $t_{от}$. We assume that the index S (country code) characterizes the quality of fabrication of excavator. This quality of the accepted set of indicators is characterized by two criteria - operation resource before overhaul $t_к$ and time between failures $t_{от}$. Intuitively (heuristically) it is clear that the higher the values $t_к$ and $t_{от}$, the better quality of production. From table 2 it is seen that the representativeness of machines in different countries varies. Therefore, cannot reliably ranking and, therefore, it is assumed that the total value is determined by the sum of values S_1 and S_2: USSR - 2+2=4; Germany - 8; France - 8; Japan - 2; USA - 8. Thus, the code values S shall be equal to: 1 - Japan; 2 - USSR; 3 - Germany, France, USA. Because of the low representativeness rank S = 3 was adopted for three countries (remember - this was before 1991).

Table 2 - Calculate values of indicator S

Country	Car brand	$t_к$, h	S_1	$t_{от}$, h	S_2
USSR	ЭО-3122	8200	2	180	2
	ЭО-3221	8250		180	
	ЭО-3323	8380		190	
	ЭО-4121Б	9550		200	
	ЭО-4125	10000		220	
	ЭО-4321Б	9150		170	
	ЭО-5124(1)	10500		180	
	ЭО-5124(2)	10500		180	
	ЭО-5124-2(1)	10500		180	
	ЭО-5124-2(2)	10500		180	
	Average	9553		184	
Germany	PH-5	8200	4	170	4
	R900	8000		190	
	MH-5	8000		170	
	R932	9100		160	
	A922	9100		170	
	2202E-НД	10500		160	
	Average	8850		170	
France	75 CE	8200	5	170	3
	60 CK	8000		190	
	75PB	7860		170	
	220CKB	10500		170	
	Average	8640		175	
Japan	UH1 1	10000	1	180	1
	UH123	10000		215	
	UH1 1	10000		180	
	Average	10000		192	
USA	224	9100	3	170	5
	Average	9100		170	

As shown by the results of the simulation, even such a simple ranking of countries-manufacturers gives quite adequate mathematical models of factor analysis. Next consider the physical-technical meaning of indicators. Factors $Г$, T, V, R, S are exogenous and factors M, g, q, $t_к$

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and t_{om} is endogenous. Moreover mass index M characterizes the flow of matter, which consists of nodes and units within the functional structure of an excavator. The indicator g is irrelevant to the rock volume (cubic capacity) and characterizes the performance of cyclic operation. The criterion q is quantitative displays the energy flow through the motor cars in the process of digging. Indicators $t_к$ and t_{om}, as already noted, characterize the activity of the driver and dredge in the course of excavation works.

IV. RANK DISTRIBUTIONS PARAMETERS OF EXCAVATORS

Further conducted factor analysis of the data of table 1 by nine factors (without regard to code group of countries S). Ranking distribution of the parameter values (factor) vector «better $\to$ worse» always modeled by an exponential law in the form of the equation:

- with the deterioration of declining values $V\uparrow$, $R\uparrow$, , $t_к\uparrow$, $t_{om}\uparrow$

$$y = y_0 \exp(-ar^b)\,; \qquad (1)$$

- when deteriorating with increasing values $\Gamma\downarrow$, $T\downarrow$, $M\downarrow$, $g\downarrow$, $q\downarrow$

$$y = y_0 \exp(ar^b)\,, \qquad (2)$$

where r - rank preferences «better $\to$ worse», $r = 0,1,2,3,\ldots$; y - dependent factor or index; y_0 - the initial value of the index in case of zero rank; a, b - parameters of the models (1) and (2), taking specific numerical values in each example simulation, identification of the exponential law, on statistical source data. In formulas (1) and (2) exponential laws: a - activity recession or growth; b - intensity exponential decay or growth.

V. RATING EXCAVATORS

The sum of ranks Σr all options allows you to determine the rating of brands of machine, and at the different manufacturers located in the different countries This method does not require mathematical modeling data in table 1 and therefore allows you to quickly assess a homogenous group (family) machines (previous technical decisions) on specific brands. For the rating table 1 replaced in table 3 on ranks. There were specified 25 brands at the sum of ranks nine parameters excavators. On a vector of «better $\to$ worse» we will place values of parameters of excavators: $\Gamma\downarrow$ - size group of excavator: than it is less, the better; $T\downarrow$ - type of a running gear (at cost): than it is less, the better; $M\downarrow$ - mass of the excavator the operational: than it is less, the better; $V\uparrow$ - bucket capacity: than it is more, the better; $R\uparrow$ - kinematic depth of digging: than it is more, the better; $g\downarrow$ - operating cycle of the company: for performance than it is less, the better; $q\downarrow$ - specific fuel consumption: than it is less, the better; $t_к\uparrow$ - motor potential: than it is more, the better; $t_{om}\uparrow$ - time between failures: than it is more, the better. When performing rank evaluations removed the «curse of dimensionality» and all parameters obtained dimensionless values that are directed along one vector of the preorder preferences «better worse». Then the ranks of all indicators put together. Here, it is assumed that all options are equivalent. A weighting factor (a measure of comparative significance) at all parameters the identical, equal to one. First place is brand ЭО-4321Б «Liebherr», Germany. The second place is the excavators models ЭО-3122 and ЭО-3323 Russian (USSR) production. The third place in the rating of brands of excavators took also of the domestic machine ЭО-3221. It follows that, if the source data is reliable and not rigged, excavators as a whole in the USSR was at the highest technical level.

VI. RATING INFLUENCING PARAMETERS AND ASSOCIATED INDICATORS

Full correlation matrix with a rating of influence of parameters of caterpillar tractors and dependent parameters are given in table 4. The coefficient of functional connectivity (correlative variations as certain populations of one species functioning) of the nine technical factors equal 53.7553 / 9^2 = 0.6636. This criterion applies when comparing different groups (systems, complexes and other) machines and equipment. Comparison with caterpillar tractors shows that uniform technical solutions of the same plant give functional connectivity in 0.7994 / 0.6635 = 1.205 times more in comparison with excavators. Among the factors influencing first place was occupied by the operating weight of the excavator. In second place is the capacity of a ladle reverse shovel and on the third - dimensional group excavator. Average time of no-failure operation got the last ninth place. Equation rating influencing parameters (Fig. 1) has the form

$$\Sigma R_x = 7{,}52061\exp(-0{,}020926 I_x^{\;1{,}32165}) - \\ - 6{,}87788\cdot 10^{-27} I_x^{\;27{,}87236}\,. \qquad (3)$$

As can be seen from the graph of the formula (3), time to failure as contributing factor dramatically reduces the amount of correlation coefficients.

Table 3- The ranking technical data single-bucket full-circle hydraulic excavators

№	Brand of the excavator, firm, country	$r_Г$	r_T	r_M	r_V	r_R	r_g	r_q	$r_к$	r_{om}	$Σr$	Rating
1	ЭО-3122	0	0	5	8	13	0	1	7	4	38	2
2	75 CE «Poquelin», France	0	0	6	10	15	9	6	7	5	58	14
3	PH-5 «Orenstein-Koppel», Germany	0	0	7	9	14	2	12	7	5	56	13
4	ЭО-3221	0	1	2	12	9	1	5	6	4	40	3
5	R 900 «Liebherr» Germany	0	1	8	11	6	6	7	8	3	50	9
6	60 CK «Poquelin», France	0	1	0	13	10	9	6	8	3	50	9
7	ЭО-3323	0	2	1	8	17	0	2	5	3	38	2
8	75 PB «Poquelin», France	0	2	4	7	18	9	6	9	5	60	15
9	MH-5 Germany	0	2	3	9	16	2	12	7	5	56	13
10	ЭО-41121Б	1	0	12	5	7	4	8	2	2	41	4
11	UH121 «Hitachi», Japan	1	0	15	6	5	10	10	1	4	52	10
12	R 932 «Liebherr», Germany	1	0	13	5	5	10	10	4	6	54	12
13	ЭО-4321Б «Liebherr», Germany	1	0	14	5	2	3	3	1	0	29	1
14	YH 123 «Hitachi», Japan	1	0	15	6	4	10	7	1	1	45	6
15	R 932 «Liebherr», Germany	1	0	13	5	5	10	10	4	6	54	12
16	ЭО-4321Б	1	2	9	6	12	5	0	3	5	43	5
17	A 932 «Liebherr», Germany	1	2	11	6	8	7	10	4	5	54	12
18	224 «Caterpillar», USA	1	2	10	6	11	8	11	4	5	58	14
19	ЭО-5124(1)	2	0	17	0	5	12	9	0	4	49	8
20	ЭО-5124(2)	2	0	17	3	2	12	13	0	4	53	11
21	220 CKB «Poquelin», France	2	0	20	1	0	14	16	0	5	58	14
22	UH 181 «Hitachi», Japan	2	0	19	4	3	11	15	0	4	58	14
23	ЭО-5124-2(1)	2	0	16	0	5	12	9	0	4	48	7
24	ЭО-5124-2(2)	2	0	16	3	2	12	13	0	4	52	10
25	2202E-НД «Atlas», Germany	2	0	18	2	1	13	14	0	6	56	13

Table 4 - Correlation matrix of full factorial analysis and ranking factors

Influencing factors (parameters x)	Dependent factors (indicators y)									Sum $ΣR$	Place I_x
	$Г$	T	M, t	V, m^3	R, m	g, sec	q, g/m^3	$t_к$, h	t_{om}, h		
Dimensional group $Г$	1	0.4710	0.9851	0.9548	0.8223	0.7659	0.7213	0.9576	0.1900	6.8680	3
Type chassis T	0.4980	1	0.6230	0.6170	0.6440	0.5000	0.3390	0.6510	0.1610	5.0330	8
Mass of the excavator M, t	0.9818	0.5710	0.9703	0.9437	0.8790	0.7906	0.8917	0.9722	0.4730	7.4733	1
Ladle capacity V, m^3	0.9874	0.4700	0.9849	0.9920	0.8759	0.7866	0.8208	0.9466	0.0940	6.9582	2
Digging depth R, m	0.8225	0.6480	0.8602	0.7040	0.9880	0.7345	0.7742	0.8594	0.2140	6.6048	4
Digging cycle g, sec	0.7771	0.4740	0.8494	0.7370	0.7114	0.9898	0.8055	0.8249	0.2530	6.4221	5
Fuel consumption q, g/m^3	0.6510	0.3510	0.7376	0.5730	0.5950	0.6530	0.9842	0.5710	0.4600	5.5758	7
Resource before overhaul $t_к$, h	0.9532	0	0.9509	0.9192	0.8530	0.7240	0.5730	0.9901	0.1310	6.0944	6
Time between failures t_{om}, h	0.0730	0.1520	0.0590	0.0950	0.2200	0.3380	0.3460	0.1320	0.9987	2.4137	9
Sum $ΣR$	6.7440	4.1370	7.0204	6.5357	6.5886	6.2824	6.2557	6.9048	2.9747	53.7553	-
Place of Indicator I_y	3	8	1	5	4	6	7	2	9	-	0.6636

Among dependent factors on the first place went again operating weight excavator. The second place was occupied resource (80% gamma resource) before overhaul, and the third was again left dimensional group excavator. Rating dependent parameters (Fig. 1) has obtained regularity

$$ΣR_y = 14{,}18507\exp(-0{,}71175 I_y^{\,0{,}021866}) -$$
$$. \quad -1{,}88693\cdot 10^{-5} I_y^{\,5{,}57107}. \qquad (4)$$

Time between failures here also received also the last ninth place. This fact, apparently, indicates a lack of precision measurements of one of the most important indicators of the reliability of the machine. Need not the average arithmetic value time between failures, and the regularities of the distribution in time depending on the mode (heavy, medium and light) work of the machine.

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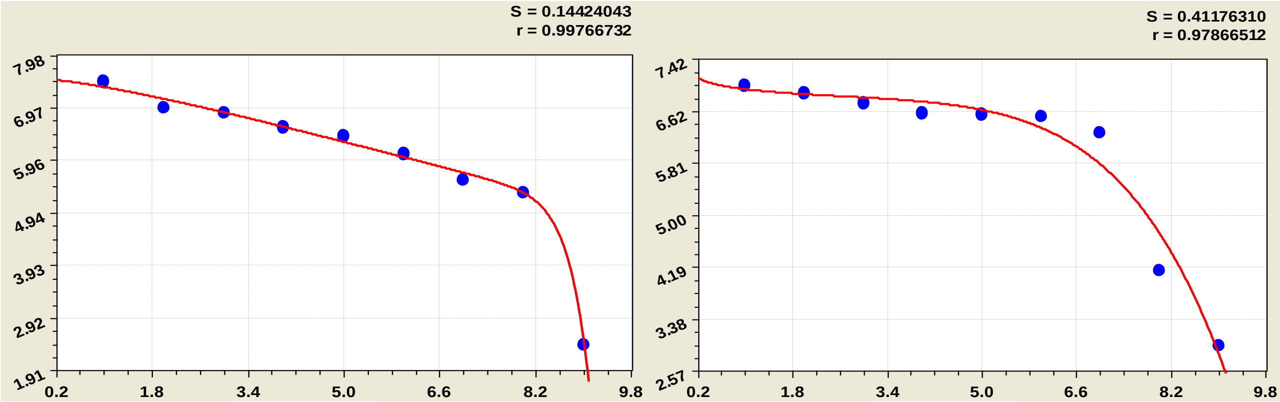

graph models (3) graph models (4)

Fig. 1. Affect (3) and dependent (4) factors on the sum of the correlation coefficients from table 4

VII. THE EQUATION OF THE DETERMINED MODEL

The correlation matrix of the full factorial analysis according to table 4 is received without wave regularities, but only on the basis of tendencies (trends). The general equation of the determined tendency (trend) for all factorial relations has an appearance

$$y = a_1 x^{a_2} \exp(-a_3 x^{a_4}) + a_5 x^{a_6} \exp(-a_7 x^{a_8}) \,, \qquad (5)$$

where y - indicator or dependent quantitative factor; x - explanatory variable or contributing factor (parameter); $a_1 .. a_8$ - parameters of the model (5), obtained during the parametric identification.

VIII. BINARY RELATIONS BETWEEN FACTORS

For the analysis of binary patterns exclude rank distributions counted factors and obtain the correlation coefficients shown in table 5. In total it turned out $9^2 - 9 = 72$ biotechnical regularities in the form of the generalized formula (5) therefore because of a large number of models further we provide in article only part from them at which the correlation coefficient is more or equally 0.7. Then the average, weak and rather weak factorial connection exclude (table 6), leaving for analysis biotechnical laws with stronger and stronger crowding factor due to binary relations.

Table 5 - Correlation matrix of all binary relations of factors of excavators

Influencing factors (parameters x)	Dependent factors (indicators y)								
	Γ	T	M, tons	V, m^3	R, m	g, sec	q, g/m^3	$t_к$, h	t_{om}, h
Dimensional group Γ		0,4710	0,9851	0,9548	0,8223	0,7659	0,7213	0,9576	0,1900
Type chassis T	0,4980		0,6230	0,6170	0,6440	0,5000	0,3390	0,6510	0,1610
Mass of the excavator M, tons	0,9818	0,5710		0,9437	0,8790	0,7906	0,8917	0,9722	0,4730
Ladle capacity V, m^3	0,9874	0,4700	0,9849		0,8759	0,7866	0,8208	0,9466	0,0940
Digging depth R, m	0,8225	0,6480	0,8602	0,7040		0,7345	0,7742	0,8594	0,2140
Digging cycle g, sec	0,7771	0,4740	0,8494*	0,7370	0,7114		0,8055	0,8249	0,2530
Fuel consumption q, g/m^3	0,6510	0,3510	0,7376	0,5730	0,5950	0,6530		0,5710	0,4600
Resource before overhaul $t_к$, h	0,9532	0,0000	0,9509	0,9192	0,8530	0,7240	0,5730		0,1310
Time between failures t_{om}, h	0,0730	0,1520	0,0590	0,0950	0,2200	0,3380	0,3460	0,1320	

Note. * Two wave regularities were in addition received.

Table 6 - Matrix binary relationships with a correlation coefficient $R \geq 0{,}7$

Influencing factors (parameters x)	Dependent factors (indicators y)						
	Γ	M, т	V, m^3	R, m	g, sec	q, g/m^3	$t_к$, h
Dimensional group Γ		0,9851	0,9548	0,8223	0,7659	0,7213	0,9576
Mass of the excavator M, tons	0,9818		0,9437	0,8790	0,7906	0,8917	0,9722
Ladle capacity V, m^3	0,9874	0,9849		0,8759	0,7866	0,8208	0,9466
Digging depth R, m	0,8225	0,8602	0,7040		0,7345	0,7742	0,8594
Digging cycle g, sec	0,7771	0,8494	0,7370	0,7114		0,8055	0,8249
Fuel consumption q, g/m^3		0,7376					
Resource before overhaul $t_к$, h	0,9532	0,9509	0,9192	0,8530	0,7240		

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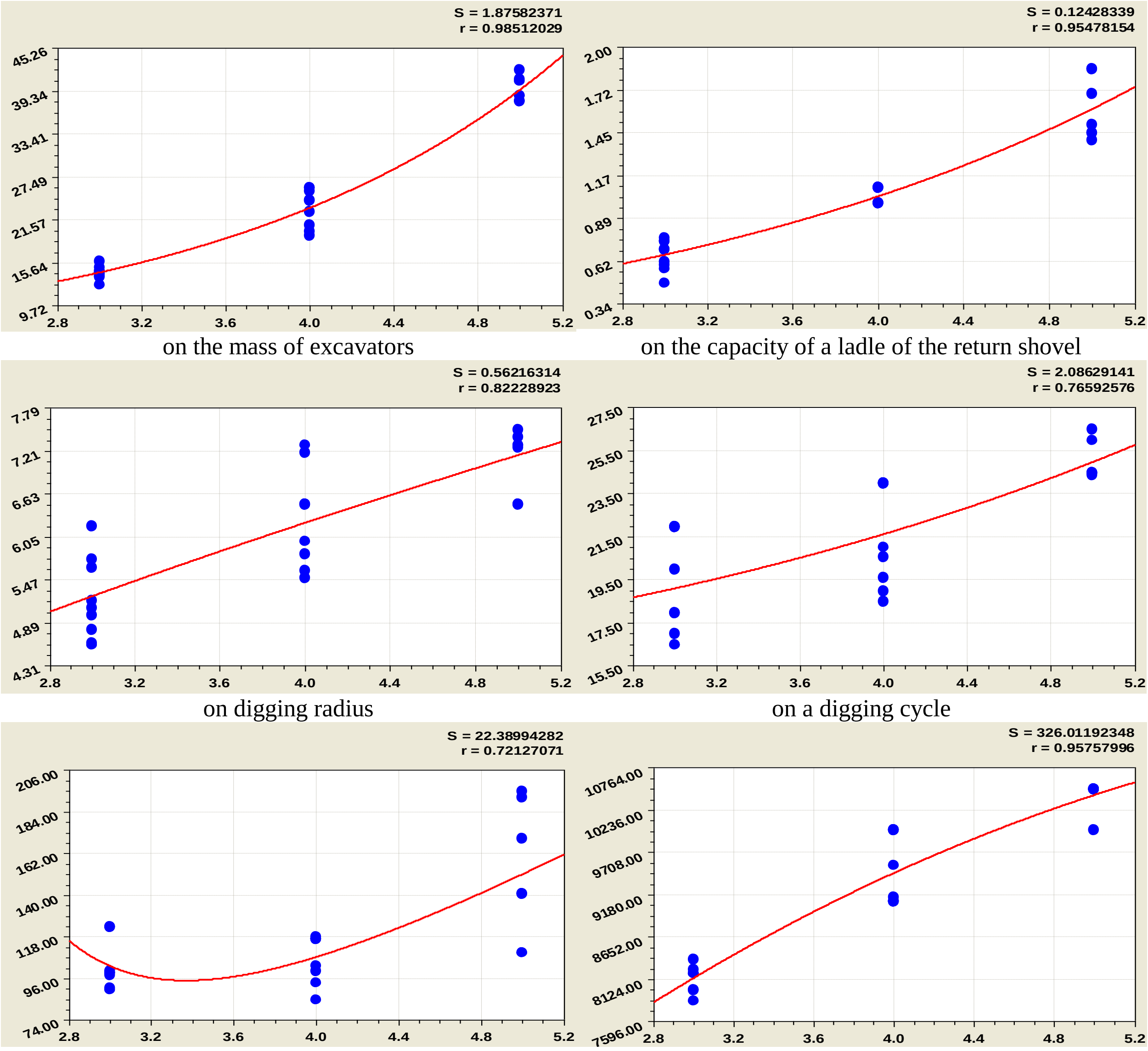

on the mass of excavators; on the capacity of a ladle of the return shovel; on digging radius; on a digging cycle; on specific fuel consumption; on a resource before overhaul

Fig. 2. The influence of the size groups (abscissa) single-bucket excavators on other parameters (ordinate)

At establishment of initial requirements to narrowness of factorial communication on correlation coefficient not less than 0.7 (admissible level of adequacy of a formula), column of time between failures, and also the column and row type of chassis are excluded. Beginning from table 6 is taken first impact factor and respect him are discussed line by line all dependent factors.

Other factors detail is given in the brochure [2].

IX. INFLUENCE OF DIMENSIONAL GROUP OF THE EXCAVATOR

On operational mass of the excavator its dimensional group is affected by the formula (Fig. 2) law of exponential growth

$$M = 5{,}31261\exp(0{,}21886\Gamma^{1{,}37773})\,. \qquad (6)$$

According to the formula (18), which took the second place in the hierarchy of the strongest in the cramped factor communication patterns, the minimum weight of the machine will be 5.3 tons.

Influence of dimensional group on the capacity of a ladle of the return shovel turned out in the form of the equation

$$V = 0{,}12587\exp(0{,}66349\Gamma^{0{,}83504})\,. \qquad (7)$$

Minimum admissible capacity of a ladle is equal 0.126 m^3.

On the radius of digging (fig. 2) influence happens on a formula

$$R = 0{,}0012802\exp(7{,}69262\Gamma^{0{,}071378})\,. \qquad (8)$$

The minimum radius almost reaches zero value.

On the operating cycle of the company (Fig. 2) size group influences so:

$$g = 15{,}45064\exp(0{,}036794\Gamma^{1{,}59672})\,. \qquad (9)$$

Minimum possible running cycle is equal 15,45 sec. Apparently, only upon transition to the principled new ***physical principles of***

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action it will be possible to achieve further increase of productivity of functioning of the excavator on a running cycle.

Specific fuel consumption (Fig. 2) by size group depends binomial formula

$$q = 18318{,}54\exp(-2{,}03470Г) +$$
$$+9{,}23319Г^{1{,}73463}\exp(-6{,}25741\cdot 10^{-8}Г). \quad (10)$$

At 90-100 times higher fuel consumption is achieved with the provided $Г = 0$ i.e. in the miniaturized excavators.

On a resource before overhaul (the sixth place among the strongest binary relations with correlation coefficient more than 0.95) according to the schedule in figure 2 the formula was received

$$t_к = 2876{,}3234\exp(0{,}0086645Г^{0{,}99985}) +$$
$$1959{,}5641Г^{1{,}31619}\exp(-0{,}15724Г). \quad (11)$$

On the first component of model (11) with growth of dimensional group of excavators increases reliability of the machine on a 80 percent resource of time of functioning to capital repairs. Then it turns out that the size is important not only in activity of animals and plants, but also technical means also in the technique. Maximum permissible mass of the excavator

Size group $Г$ excavator operating weight with a basic working equipment specified in GOST 30067-93:

1 – to 6.3 tons;
2 – from 6.3 to 10 tons;
3 – from 10 to 18 tons;
4 – from 18 to 32 tons;
5 – from 32 to 50 tons;
6 – from 50 to 71 tons.

In table 7 it is provided and the offered (leveled) scale of dimensional group with the minimum and maximum operational weight.

For minimum weight was obtained (fig. 3a), the equation

$$[M_{\min}] = 0{,}63007\exp(1{,}40645Г^{0{,}63386}). \quad (12)$$

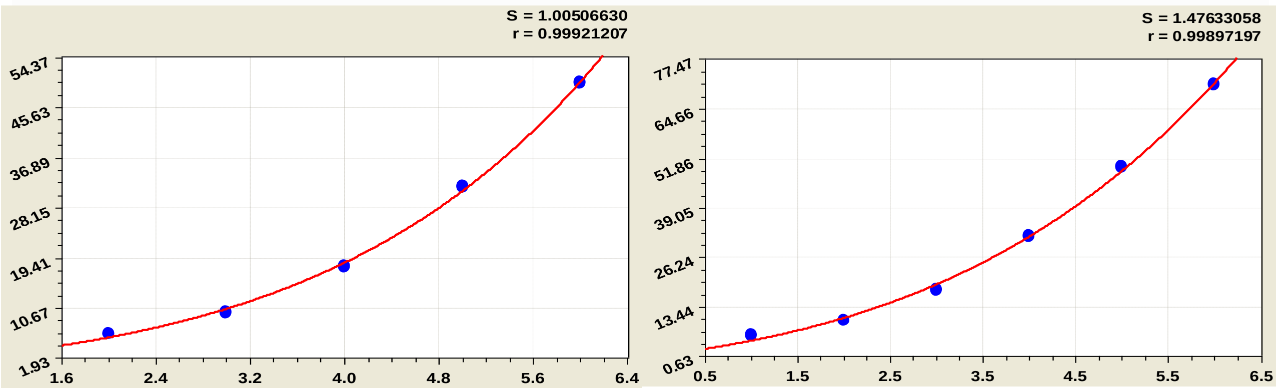
On the maximum weight the formula is identified (fig. 3b)

$$[M_{\max}] = 0{,}52749\exp(2{,}20759Г^{0{,}44617}). \quad (13)$$

Proposed in table 7 scale limit mass excavator contains 11 dimensional groups, six groups have in GOST 30067-93.

Table 7- The maximum permissible mass of dimensional groups single-bucket full-circle hydraulic excavators, tons

Dimensional group $Г$	on GOST 30067-93		by model (12) and (13)		Proposed scale	
	$[M_{\min}]$	$[M_{\max}]$	$[M_{\min}]$	$[M_{\max}]$	$[M_{\min}]$	$[M_{\max}]$
00	-	-	-	-	0,0	0,6
0	-	-	0,63	0,53	0,6	2,6
1	-	6,3	2,57	4,80	2,6	6,3
2	6,3	10	5,59	10,68	6,3	10
3	10	18	10,59	19,38	10	18
4	18	32	18,63	31,76	18	32
5	32	50	31,16	48,77	32	50
6	50	71	50,25	71,57	50	71
7	-	-	78,76	101,52	71	100
8	-	-	120,65	140,21	100	140
9	-	-	181,31	189,50	140	180



a) on a minimum in model (12) b) to the maximum in model (13)

Fig. 3. The maximum permissible mass of single-bucket full-circle hydraulic excavators

as continuations of extremities of the person.

This fact once again convincingly proves that biotechnical regularities on a basis identification of steady laws are applicable everywhere – not only in biology and ecology, but

Operating weight of up to 6,3 tons is divided into three intervals:

00 – micro excavators with a limit weight to 0.6 tons (600 kg);

0 - small-sized excavators weight from 0,6 to 2,6 tons;

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1 – first dimensional group from 2.6 to 6.3 tons. Most often, these excavators are equipped wheeled movers.

Next, we consider nine strongest ties with acceptable correlation coefficient $R \geq 0.95$.

The strongest factor connection**.** For compact recording identified biotechnical laws applies a matrix (table. 8). Given nine laws are enough to make a mathematical model for calculation justification of parameters of the newly created models of machines.

After association of all members the trinomial equation (fig. 4) of communication $g \to M$ received a look

$$M = M_1 + M_2 + M_3, \qquad (15)$$

$$M_1 = 4{,}64897\exp(0{,}0033451 g^{2{,}00335}),$$

$$M_2 = A_1 \cos(\pi g / p_1 + 1{,}34961),$$

$$A_1 = -3{,}65010 \cdot 10^{-41} g^{39{,}25125} \exp(-0{,}31903 g^{1{,}41760}),$$

$$p_1 = 58{,}69503 - 1{,}26193 g^{1{,}13298},$$

Table 8 - The matrix parameters biotechnical patterns (5) the strongest binary factor relations with $R \geq 0{,}95$

Structure of influence	Model $y = a_1 x^{a_2} \exp(-a_3 x^{a_4}) + a_5 x^{a_6} \exp(-a_7 x^{a_8})$								Correlation coefficient
	First component of the model (1)				Second component (1)				
	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	
1. $V \to \Gamma$	5,02715	0	0	0	-2,19084	0	0,59624	4,76822	0,9874
2. $\Gamma \to M$	5,31261	0	-0,21886	1,37773	0	0	0	0	0,9851
3. $V \to M$	14,96404	0	0,24570	1	15,18409	5,13901	0,44086	2,82534	0,9849
4. $M \to \Gamma$	0,48070	0,76460	0,016915	0,90630	0	0	0	0	0,9818
5. $M \to t_к$	46977,83	0	0,29604	1	1532,55	0,60758	9,24027e-5	2,21242	0,9722
6. $\Gamma \to t_к$	2876,3234	0	-0,0086645	0,99985	1959,5641	1,31619	0,15724	1	0,9576
7. $\Gamma \to V$	0,12587	0	-0,66349	0,83504	0	0	0	0	0,9548
8. $t_к \to \Gamma$	0,59130	0	-0,00020228	1	0	0	0	0	0,9532
9. $t_к \to M$	0,42503	0	-0,00042953	1	0	0	0	0	0,9509

For example, initially set to the capacity of a ladle reverse shovel excavator. Then the formulas № 1 and № 3 are calculated size group and mass excavator. After formula № 5 is calculated amount of time before overhaul, and for other equations are checked settings. For expanded calculations to table 8 others are added from the revealed statistical models at correlation coefficient $R \geq 0{,}9$, and if necessary - from level $R \geq 0{,}8$ etc.

X. AMPLIFICATION FACTOR VIBRATIONAL COMMUNICATION ADAPTATION

In the nature any adaptation to environment at animals and plants happens on positive oscillatory indignation [3]. Excavators in the parameters enter oscillatory change on an improvement way through oscillatory behavior of founders – designers, technologists. We will give an example (fig. 4) of oscillatory adaptation of influence of a running cycle of digging g on change of operational mass of the excavator. Deterministic model (Fig. 4) is a kind of law of exponential growth

$$M = 8{,}10931\exp(0{,}00026952 g^{2{,}67184}). \qquad (14)$$

From figure 4 it is visible that the first wave function has high adequacy at correlation coefficient 0.8759. This fluctuation significant. Thus the remains after a trend (14) are also significant. The coefficient of correlation 0,7698 also refers the second oscillatory indignation to strong factorial communications between a running cycle of digging and operational mass of the excavator.

$$M_3 = A_2 \cos(\pi g / p_2 - 1{,}60440),$$

$$A_2 = -5{,}25569 \cdot 10^{-98} g^{103{,}30053} \exp(-1{,}44324 g^{1{,}35664}),$$

$$p_2 = 0{,}75208 + 0{,}0097696 g^{1{,}04346}.$$

Negative signs before the amplitudes A_1 and A_2 show crisis excitement. Thus half-cycles p_1 and p_2 oscillatory indignation of operational weight with increase of a running cycle of digging of the excavator in the first wave decrease (frequencies of fluctuation increase), and in the second wave of indignation increase (frequencies of fluctuation decrease).

Thereby on the first fluctuation founders of excavators enter a tremor, and on the second – calm down concerning an indicator.

XI. CONCLUSION

Excavator and its functional assembly units can be used as base modules in the manufacture of new manipulator types of machinery and their working bodies [3]. Parametric series of machines, work equipment and working bodies can be created by applying all size groups of excavators, existing in the world. The most effective are machines on the base of excavators dimensional groups 3, 4 and 5, when instead of the bucket set of replaceable working bodies. The first place in the rating of up to 1991 he served brand ЭО-4321Б « Liebherr », Germany. The second place models ЭО-3122 and ЭО-3323 soviet production. The third place in the rating of brands of excavators took also of the domestic machine ЭО-3221.

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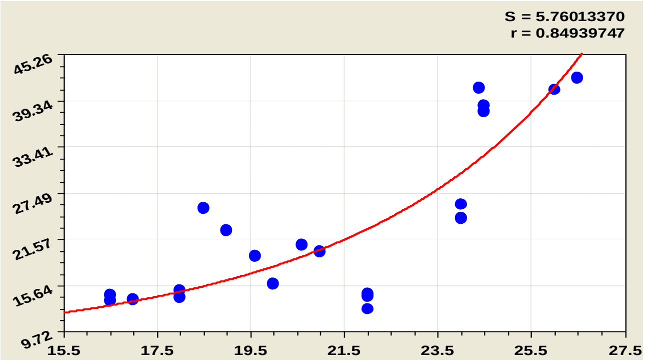
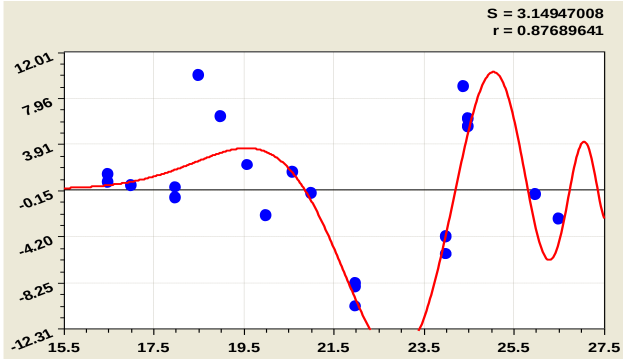
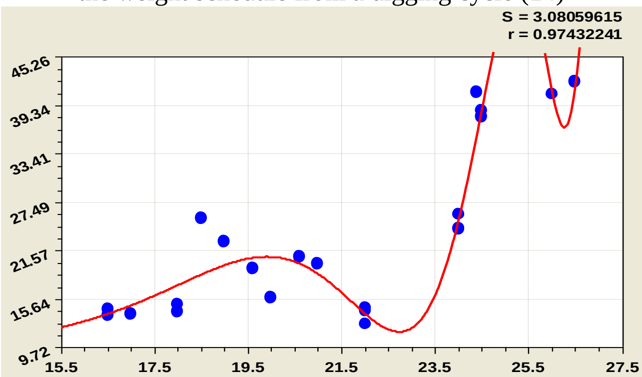


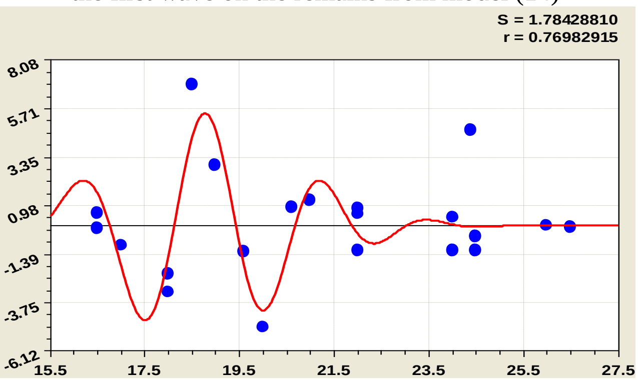
the weight schedule from a digging cycle (14)



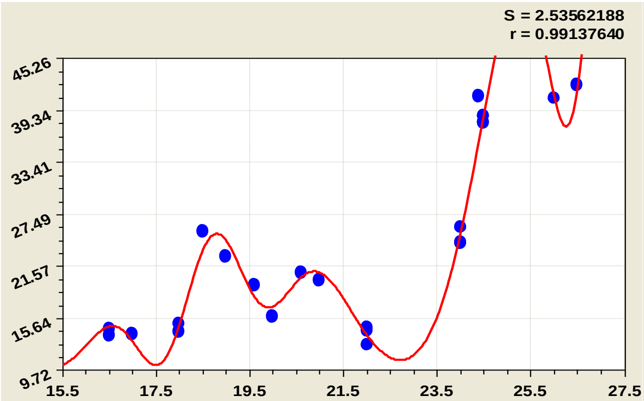
the first wave on the remains from model (14)



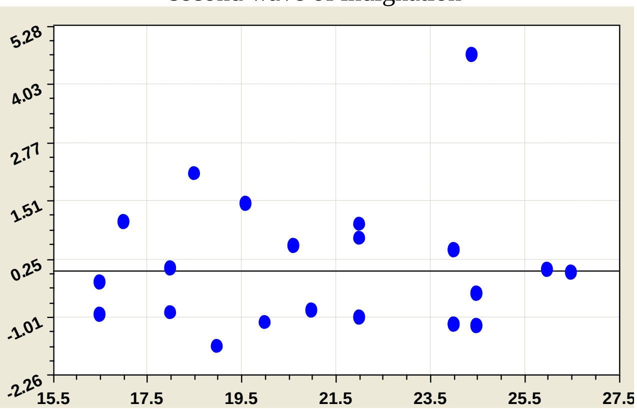
trend and first wave



second wave of indignation



the weight schedule from a digging cycle (15)



the remains from model (15)

Fig. 4. Oscillatory influence of a cycle of digging (abscissa) on weight excavator (ordinate)

But these achievements weren't used for development (functional expansion) standard sizes and for other branches of national economy in Russia. Preparation of initial information when modeling has crucial importance. In connection with insufficient completeness table 1 on many manufactured in the world excavators and for many consider the technical and economic indicators (by cards of the technical level and quality of production) presented the mathematical models are approximate and methodical character. Excavator ЭО-4125 soviet production could become a base for the creation internationally competitive family manipulator forest machines. Many of them us in due time were protected by copyrights and patents for inventions [3].

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