ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 5, Issue 3 , March 2018

Mathematical model of the Norm of Electric Energy Consumption on the Excavation of Rock Mass in the Processes of Ore Preparation

Olimjon Toirov

Senior Researcher, Doctor of Philosophy, Laboratory of Electro Mechanics and Technological Equipment in Power Engineering, Scientific-Technical Center JSC "Uzbekenergo", Tashkent, Uzbekistan

ABSTRACT: In order to determine the energy efficiency of production was conducted energy and instrumental survey of individual consumers of the main technological equipment of the quarry. Instrumental examination included the measurement and testing of individual electric energy receivers of basic and auxiliary equipment of a mining excavator for the technological line on the excavation of $1m^3$ of rock mass. Based on the results of instrumental measurements of electric energy consumption on the excavation of 1 m^3 of rock mass, the distribution of variables as a function of time on histograms is constructed. Mathematical processing of conducted instrumental measurements on the energy efficiency of electric energy consumption with the excavation of $1m^3$ of rock mass, the degree of raw material loading has a significant impact on technological equipment. As a result of the regression analysis, a mathematical model of the norm of electric energy consumption as a function of the consumed electricity and excavation of the rock mass was obtained, in which the coefficients of the model are significant and reliable.

KEYWORDS: mathematical model, regression analysis, norm, energy efficiency, career excavator

I.INTRODUCTION

In the careers of the mining industry the main technological equipment are the drilling rigs and excavators, from which the power-consuming equipment are single-bucket excavators and the effectiveness of the use of their depends essentially the work of the mining enterprise. The main indicator of existing excavators is energy efficiency of their work [1].

The efficiency of production is determined by the specific consumption of fuel and energy resources per unit of output, as well as for each structural subdivision of the enterprise [2]. In this regard, the necessary condition for production efficiency is the development of progressive scientifically grounded norms for the expenditure of fuel and energy resources for each workshop and, in general, for the plant.

Energy efficiency - scientifically based absolute or specific value of consumption of fuel and energy resources resources on manufacture of a unit of production (works, services) of any purpose. Or in other words efficiency as a matter of fact is norm of the expense in particular electric energy on manufacture of a unit of production of the established quality [3]. The development of scientifically-based norms is quite labor-intensive, requiring the development of methodological approaches, skilled and painstaking work, taking into account all aspects in the production of products.

As experience in the operation of electrical equipment shows, the calculation of the electric load by the calculation method is a roughly approximate method of estimating the design load and therefore, in general, can only be recommended for preliminary calculations of the power supply system units including a significant number of electric energy receivers (department, shop, hull or plant as a whole). In this regard, to determine the electrical load, we use the instrumental method of examining the main and auxiliary equipment [4].

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 5, Issue 3 , March 2018

Instrumental survey is the most important stage of the work, which requires considerable expenditures. This is due to the fact that in the course of work several modern devices are installed, installed at all inputs of consumers. In addition, the survey, as a rule, cannot be carried out in one stage, since measurements, depending on the technological regime, must be carried out with different options for loading equipment, which makes certain requirements for changing the actual technological cycle of energy consumption. Only qualitatively carried out instrumental survey allows to receive the objective and reliable information necessary for an estimation of power consumption of object of inspection and development of norms of the charge of electric energy on a unit of production.

II. RESEARCH PROBLEM AND RESEARCH METHODOLOGY

In this regard, for calculating the norms of electric energy consumption on a $1m^3$ mining mass, a combined method of normalization is used - a method of developing norms for the consumption of electric energy using two or three methods simultaneously: calculation-analytical, experimental and statistical.

The main goal of scientific research consists in showing the statistical importance of effect of influence of the certain factor on a studied dependent variable and definition, at what combination of levels of external and internal factors the fullest can be received and a trustworthy information about behavior of system [5-7, 9].

Mathematical modeling is a method of the qualitative or quantitative description of objects or processes, while the real object, process or phenomenon is simplified, schematized and described by the certain equation [8, 10].

In most cases, the mathematical model is a regression equation, that is, the geometric place of the points of mathematical expectations of conditional distributions of the objective function. The main difficulty at the stage of formulation of the problem is the transition from the language of the specialty to the language of planning the experiment, into the language of mathematics.

The construction of a mathematical model of the technological process, depending on the task, can pursue the following objectives: to minimize energy consumption, improve reliability, etc .; increase the reliability and speed of management, increase the effectiveness of quality control, create conditions for automation of the management process, etc.

The problem of determining the functional dependence, which best describes the experimental data, is connected with overcoming of some fundamental difficulties. In the general case, for the standardized data, the functional dependence of the exponent on the parameters can be represented in the form [4, 7-8].

$$y = f(u_1, u_2, \dots, u_m) + \varepsilon \tag{1}$$

where f - in advance unknown function which is subject to definition;
ε - an error of approximation of empirical data.

This equation is usually called the sampling equation of regression y on u . This equation characterizes the relationship between the variation of the exponent and the variations of the factors. A measure of correlation measures the proportion of the variation of the indicator, which is related to the variation of factors. In other words, the correlation of the indicator and factors cannot be treated as a link between their levels, and regression analysis does not explain the role of factors in the creation of the indicator.

Simple, convenient for practical application is the class of polynomial functions

$$y = a_0 + \sum_{j=2}^{m} a_j u_j + \sum_{j=2}^{m-1} \sum_{k=j+1}^{m} a_{jk} u_j u_k + \sum a_{jj} u_j^2 + \ldots + \varepsilon. \tag{2}$$

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 5, Issue 3 , March 2018

For such a class, the problem of selecting a function reduces to the problem of selecting the values of the coefficients $a_0, a_j, a_{jk}, ..., a_{jj}$ ... .

However, the universality of a polynomial representation is ensured only if there is the possibility of an unlimited increase in the degree of a polynomial, which is not always permissible in practice; therefore, it is necessary to apply other types of functions.

Widely used in practice, is a first-degree polynomial or a linear regression equation, which we will use for determine the regression equation for calculating the electric energy consumption norms on per 1 m^3 of rock mass [4, 9].

$$y = a_0 + \sum_{j=2}^{m} a_j u_j + \varepsilon . \qquad (3)$$

If the linear model is inaccurate or the parameters are not accurately measured, then in this case the method of least squares allows to find such values of the coefficients at which the linear model best describes the real object in the sense of the chosen criterion of standard deviation.

All electrical energy costs are to be normalized not only for the extraction of one meter of cubic rock, on loading of one ton of ore, on drilling one running meter of the well as the main production, but also auxiliary technological processes and production - operational needs. In this regard, energy efficiency of work of excavators of the mining and metallurgical industry is considered from the standpoint of rationing of the consumption of electric energy on excavation of 1m^3 of rock mass. With reference to the Kalmakyr JSC “Almalyk MMC”, the main task of normalizing the consumption of electric energy is to ensure the application in production of technically and economically justified norms for the consumption of electric energy for the implementation of the economy regime, rational distribution and the most effective use of them, taking into account the introduction of the achievement of scientific and technological progress, domestic savings resources, ensuring the greatest amount of ore processing with the least expenditure of electrical energy.

In order to determine the energy efficiency of production, an energy and instrumental survey of individual consumers of technological equipment of the quarry was conducted. By results of instrumental measurements of electric energy consumption on the excavation of 1m^3 of rock mass, it is constructed distribution of variables in function of time in the histogram of Figure 1.

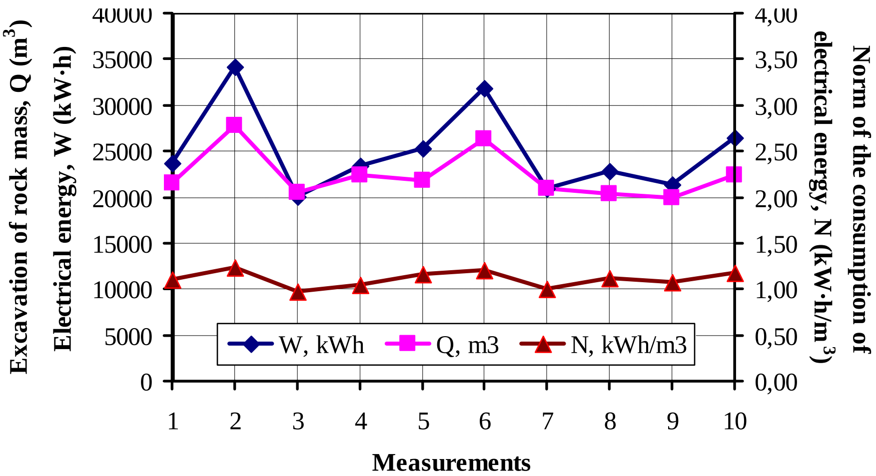

Fig. 1. Results of instrumental measurements of the consumption of electrical energy on the excavation of rock mass

When developing norms of the consumption of electric energy, calculation-analytical, experimental and statistical methods are used. Based on the results of long and complex work, using regression analysis, it is received mathematical models of specific norms.

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 5, Issue 3 , March 2018

III. RESULTS

According to the experimental data on the electric energy consumption per 1 m^3 of rock mass, the results of the grouping of the statistical data of electric energy consumption, excavation of rock mass and actual specific norms for the quarries of Kalmakyr JSC "Almalyk MMC" were determined.

Table 1. The grouping of experimental data of electric energy on the excavation of rock mass

	Frequency table: W_{ECT} - consumed electricity,(kW*h) K-S d=,21406, p> .20; Lilliefors p> .20					
Category	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
18000,00<x<=20000,00	0	0	0,00000	0,0000	0,00000	0,0000
20000,00<x<=22000,00	3	3	30,00000	30,0000	30,00000	30,0000
22000,00<x<=24000,00	3	6	30,00000	60,0000	30,00000	60,0000
24000,00<x<=26000,00	1	7	10,00000	70,0000	10,00000	70,0000
26000,00<x<=28000,00	1	8	10,00000	80,0000	10,00000	80,0000
28000,00<x<=30000,00	0	8	0,00000	80,0000	0,00000	80,0000
30000,00<x<=32000,00	1	9	10,00000	90,0000	10,00000	90,0000
32000,00<x<=34000,00	0	9	0,00000	90,0000	0,00000	90,0000
34000,00<x<=36000,00	1	10	10,00000	100,0000	10,00000	100,0000
Missing	0	10	0,00000		0,00000	100,0000

Table 2. The grouping of experimental data of excavation of rock mass

	Frequency table: Q_{ECT} - excavation of rock mass, (m^3) K-S d=,29349, p> .20; Lilliefors p<,05					
Category	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
19000,00<x<=20000,00	1	1	10,00000	10,0000	10,00000	10,0000
20000,00<x<=21000,00	3	4	30,00000	40,0000	30,00000	40,0000
21000,00<x<=22000,00	2	6	20,00000	60,0000	20,00000	60,0000
22000,00<x<=23000,00	2	8	20,00000	80,0000	20,00000	80,0000
23000,00<x<=24000,00	0	8	0,00000	80,0000	0,00000	80,0000
24000,00<x<=25000,00	0	8	0,00000	80,0000	0,00000	80,0000
25000,00<x<=26000,00	0	8	0,00000	80,0000	0,00000	80,0000
26000,00<x<=27000,00	1	9	10,00000	90,0000	10,00000	90,0000
27000,00<x<=28000,00	1	10	10,00000	100,0000	10,00000	100,0000
Missing	0	10	0,00000		0,00000	100,0000

Table 3. The grouping of experimental data of norm of electric energy consumption for excavation of rock mass

	Frequency table: N_{ECT} - norm of consumed electricity, kW·h/m^3 K-S d=,12005, p> .20; Lilliefors p> .20					
Category	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
,9500000<x<=1,000000	2	2	20,00000	20,0000	20,00000	20,0000
1,000000<x<=1,050000	1	3	10,00000	30,0000	10,00000	30,0000
1,050000<x<=1,100000	2	5	20,00000	50,0000	20,00000	50,0000
1,100000<x<=1,150000	1	6	10,00000	60,0000	10,00000	60,0000
1,150000<x<=1,200000	2	8	20,00000	80,0000	20,00000	80,0000
1,200000<x<=1,250000	2	10	20,00000	100,0000	20,00000	100,0000
Missing	0	10	0,00000		0,00000	100,0000

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 5, Issue 3 , March 2018

The results of the grouping of experimental data on electric energy consumption, excavation of rock mass and actual specific norms are presented: in Table 1 - the grouping of the electric energy consumption for the excavation; in Table 2 - the grouping of the excavation of rock mass; in Table 3 - the grouping of the norm of electric energy consumption for the excavation of rock mass.

The grouping allows presenting the primary data in a compact form, to reveal the regularities of variation.
The distribution of variables is presented in the histograms in Figures 2-4.

Figure 2 shows a histogram of the distribution of electrical energy for the excavation of rock mass, in which the curve of density of distribution is shown, as well as the Kolmogorov-Smirnov test (d). The Kolmogorov-Smirnov statistics is equal to 0.214. The smaller value of this statistic is closer distribution of the random variable to the normal. The probability of the null hypothesis (p) is more than 0.20.

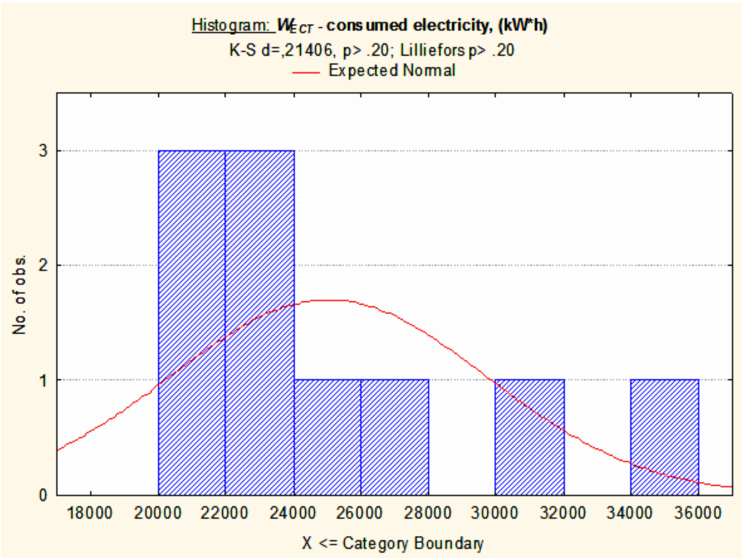

Fig. 2. Histogram of the distribution of electrical energy for the excavation of rock mass

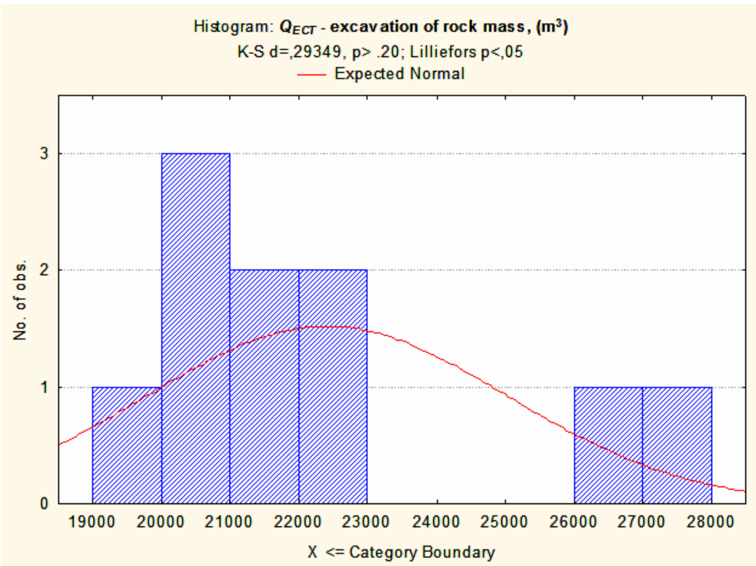

Fig. 3. Histogram of distribution of the excavation of rock mass

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 5, Issue 3 , March 2018

Figure 3 shows a histogram of the distribution of the excavation of rock mass. The Kolmogorov-Smirnov statistics is equal to 0.293. The probability of the null hypothesis (p) is more than 0.20.

Figure 4 shows a histogram of the distribution of the norm of electric energy consumption for the rock mass excavation. The Kolmogorov-Smirnov statistics is equal to 0.120. The probability of the null hypothesis (p) is more than 0.20.

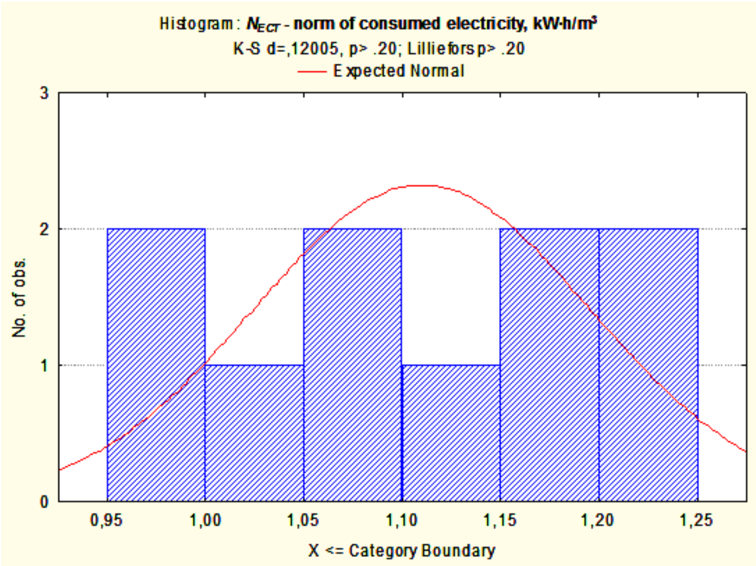

Fig. 4. Histogram of the distribution of the norm of electric energy consumption for the rock mass excavation

The histogram allows estimating "approximately" the normality of the empirical distribution. The histogram allows you to qualitatively evaluate the various characteristics of the distribution. The results of calculations of descriptive statistics are given in Table 4.

Table 4. The results of calculations of descriptive statistics

Variable	Descriptive Statistics (Spreadsheet1)						
	Valid N	Mean	Minimum	Maximum	Variance	Std.Dev.	Standard Error
W_{ECT}, (kW*h)	10	25024,19	20137,04	34221,06	22002278	4690,659	1483,316
Q_{ECT}, (m^3)	10	22407,10	19919,00	27822,00	6900970	2626,970	830,721
N_{ECT}, (kW·h/m^3)	10	1,11	0,98	1,23	0	0,086	0,027

One of the typical tasks of processing experimental data is to determine the relationship between norm of the consumption of electric energy on the excavation of rock mass to the consumed electricity and productivity. Preliminary processing includes standardization of the matrix of empirical data, calculation of correlation coefficients, and check of their significance.

Correlation analysis was carried out to establish the tightness of the interrelationships between the data obtained.
The correlation coefficient is an indicator that estimates the tightness of the linear relationship between the signs. It can take values from -1 to +1. The "-" sign means that the link is reverse, and "+" is a straight line. The closer the coefficient to |1|, the closer the linear relationship. At the value of the correlation coefficient (according to Butler) less than 0.3, the connection is estimated as weak, from 0.31 to 0.7 - significant, from 0.71 to 0.9 - close, 0.91 and higher - very close. Table 5 shows the correlation matrix of electricity consumption, productivity and the norm of electric energy consumption per ton of ore.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 5, Issue 3 , March 2018

Table 5. Correlation matrix of electricity consumption, productivity and the norm of electric energy consumption per ton of ore.

Variable	Correlations (Spreadsheet1) Marked correlations are significant at p < ,05000 N=10 (Casewise deletion of missing data) W_{ECT}, (kW*h)	Q_{ECT}, (m^3)	N, (kW·h/m^3)
W_{ECT}, (kW*h)	1,00	0,97	0,89
Q_{ECT}, (m^3)	0,97	1,00	0,75
N, (kW·h/m^3)	0,89	0,75	1,00

As can be seen from the table, there is a very close relationship between the consumed electric energy and the excavation of rock mass, as well as a significant feedback between the excavation of rock mass and the norm of electric energy consumption. The relationship between the norm of electric energy consumption and the volume of production is estimated as an inverse weak.

In accordance with this, we will perform a regression analysis of the obtained data. The main results of the regression analysis are given in table 6.

Table 6. The main results of the regression analysis

N=10	Regression Summary for Dependent Variable: **N, (kW*h/m3)** R= ,99819113 R?= ,99638553 Adjusted R?= ,99535282 F(2,7)=964,83 p<,00000 Std.Error of estimate: ,00585 Beta	Std.Err. of Beta	**B**	Std.Err. of B	t(7)	p-level
Intercept			**1,205925**	0,027882	43,2517	0,000000
W, (kW*h)	2,58265	0,089268	**0,000047**	0,000002	28,9315	0,000000
Q, (m3)	-1,74646	0,089268	**-0,000057**	0,000003	-19,5643	0,000000

Where R - the multiple correlation coefficient; R? - coefficient of determination; Adjusted R? - the adjusted coefficient of determination; F - F-test; df is the number of degrees of freedom for the F-test; p - probability of the null hypothesis for the F-test; Intercept - the free term of the equation; Beta - the coefficients of the equation; St. Err. of Beta - standard errors of odds; B - coefficients of the regression equation; St. Err. of B - standard errors of coefficients of the regression equation; t (10) - t-criteria for the coefficients of the regression equation; p-level - the probability of a null hypothesis for the coefficients of the regression equation.

IV. CONCLUSION

1. The analysis of modern methods of normalizing the consumption of electrical energy per unit of production is carried out. With reference to the Kalmakyr mine, the normalization of the consumption of electrical energy for: the extraction of one meter of cubic rock mass; Loading of one ton of ore is a combined method of rationing, combining the use of two or three methods simultaneously: calculation-analytical, experimental and statistical.

2. As a result of regression analysis obtained by a reliable mathematical model of the norm of consumption of electric energy as a function of the consumed electricity and excavation of the rock mass

$$N_{\mathrm{ECT}} = 1{,}205925 + 0{,}000047 \cdot W_{\mathrm{ECT}} - 0{,}000057 \cdot Q_{\mathrm{ECT}}$$

where N_{ECT} - norm of electric energy consumption for excavation of rock mass, kW·h/m^3; W_{ECT} - consumed electricity, kW·h; Q_{ECT} - excavation of rock mass, m^3.

All coefficients of the equation are significant at the 5% level (p-level <0.5). This equation explains 99.9% $(R? = 0{,}999)$ variation of the dependent variable. The statistical level of significance (p-level, that is, the p-level) is a

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 5, Issue 3 , March 2018

measure of confidence in its "truth" (in the sense of "representative sampling"). More precisely, the *p-level* is an indicator inversely proportional to the reliability of the result. A higher *p-level* corresponds to a lower level of confidence in the results found in the sample, for example, the dependencies between variables. Namely, the *p-level* is the probability of an error associated with the generalization of the observed result.

Thus, i.e. a mathematical model of electric energy consumption is found, which is approximated by the equation with the original data array obtained during the experiment. The analysis of the model's correspondence to the initial data allows us to speak about a sufficient degree of accuracy of the results obtained. The coefficients of the resulting linear regression equation are estimated as significant. The model is assessed as adequate.

REFERENCES

[1] Kamalov T.S., Toirov O.Z. The method of determining the energy-efficiency of career excavators of the mining industry, European Science Review, Vienna, No 3-4, 299-303, 2016.
[2] Maksimyuk E.V., Mikshina V.S. Mathematical methods and algorithms for decision support to ensure energy efficiency. Innovative information technologies, No 3, 319-321, 2014.
[3] Nevokshenov A.Yu., Udovik A.V., Yurkovskaya G.I. Factors influencing the implementation of energy saving and energy efficiency programs for industrial enterprises, Modern problems of economic and social development, No 11, 32-34, 2015.
[4] Kamalov T.S., Ishnazarov O.X. Increase of Efficiency of Use of the Electric Power Copper Concentrating Factory of Open Society “Almalyk MMC”. Uzbek Journal "Problems of Informatics and Energetics", Tashkent, No 5, 37-43, 2011.
[5] Borovikov V.P. A popular introduction to modern data analysis in the STATISTICA system. Textbook for high schools. Hot line - Telecom, Moscow, 288 p, 2013.
[6] Khalafyan A.A. Industrial statistics. Quality control, process analysis, experiment planning in the STATISTICA package. URSS, Moscow, 384 p, 2013.
[7] King Myke. Process control: A Practical Approach, Second Edition. Chichester, John Wiley & Sons Ltd., United Kingdom, 248-256, 2016.
[8] Keyhani A., Lu W., Proca B. Modeling and Parameter Identification of Electric Machines. W: Handbook of Automotive Power Electronics and Motor Devices, ed. A. Emadi, Taylor & Francis Group, USA, 449-513, 2005.
[9] http://statsoft.ru/home/textbook/modules/stexdes.html#index
[10] http://100pudov.com.ua/subject/1/4225

AUTOR’S BIOGRAPHY

Olimjon Zuvurovich Toirov, Doctor of Philosophy, Assistant Professor, Senior Researcher of Laboratory of Electro Mechanics and Technological Equipment in Power Engineering, Scientific-Technical Center JSC “Uzbekenergo”. He in 2012 has defended Ph.D dissertations. In 2016 he was awarded the academic title of senior scientific employee. Under the leadership of O.Z. Toirov as part of the "National program of the training of personnel" 5 masters theses, more than 30 bachelor’s degrees are prepared and defended. Recently, he participated in the program of the Indian Technical and Economic Cooperation (ITEC) and attended 3 months scholarship in CMC Academy, New Delhi, India. He has completed the UNESCO/Poland Co-Sponsored Fellowships Programme in Engineering, edition 2017A during the period six months in a field of study “Mining Devices” at the AGH University of Science and Technology, Krakow, Poland. He has published more than 70 papers in International and Nation Journals and Conferences.