Design of Navigation Satellite Systems in Effective Geomonitoring for Mining

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Abstract. Currently for a mining science it is actively developing branch of knowledge, called "satellite technology", which has diverse practical applications for geodesy, mine surveying, control systems, mining logistic and transport complex, ensuring the safety and control of the risks there creation of tools and methods of the implementation of energy efficiency strategies. For specialists of mine surveying and geodesy introduction of practice, satellite-positioning methods has become almost revolutionary technological revolution that led to a radical revision of the structure of geodetic support of the country, fundamental changes in the methods field and laboratory work on the earth's surface. There are examples of current uses of satellite technology over the last decade at the leading companies of the mining sector. The creation of new methods of technical and economic audit determines the need for generation and proof of the most common and objective criteria and evaluation indicators for the design phase and launch of the satellite equipment. To extend the lifetime of spacecraft is pro-posed in the schematic design phase to calculate the possible effects of electrostatic discharges and to give recommendations for reducing their negative influence. Developed a new method that allows for 2-3 orders of magnitude to reduce the complexity of calculation for the pattern of spreading of the currents on the surface of spacecraft from electrostatic discharge. The method is based by the idea of macromodeling. The accuracy of calculations is very high (the inaccuracy does not exceed 1%).

1. Introduction

From Mining as a basic industry, making a significant contribution to the economic development of the country. The most urgent problems of the industry are: reduction of overhead costs; reduced environmental and man-made risks; technological upgrading; enhancing staff training; providing a comprehensive methodological and legal support of activity of the enterprises; creation of effective system of quality control of products and services; establishing effective relationships be-tween business and government; design of integrated systems for automated and remote process control. A leading role in the field of modern innovative development in the mining industry are designed to ensure efforts on the study and development of world achievements in the field of engineering, technology and organization of production, as well as the training and retraining of personnel with a view to their adaptation to innovative activities. Currently actively forming branch of knowledge, called "satellite technology" that has a variety of practical applications with in-time surveying,
exploration, mine surveying, control systems of transport complex, ensuring the safety and control of risks in gene expression under tools and methods for the implementation of energy efficiency strategies.

Key direction of the innovative development of mining industry is the development of technologies deserted excavation and transportation of minerals using modern software and hardware systems integrated into the General management system of the mining enterprise of special significance for gain the project "Intelligent mining", where management is carried out remotely or completely automatically. The effectiveness of the use of Global navigation satellite systems (GNSS) for the mining industry in geononitoring is reflected in the renewal and replenishment of the topographic base for the areas of economic interest of mining enterprises; the definition and control of the observance of the boundaries of allotments and conservation areas; qualitative ecological monitoring of mining enterprises; comprehensive mapping of the geological formations in the exploration and calculation of reserves of mineral resources; planning capital construction and construction of infrastructure communications. GNSS is increasingly being developed in a variety of States and find the application at the enterprises of the resource sector in countries such as USA, Germany, France, UK, Canada, Chile, China, Japan. There is an objective question about the situation with the use of artificial earth satellites (AES) in the state, the first time they ran. Of course, traditionally, the priority use of the satellite technology owned by the military industrial complex. But in our country space methods have been actively involved in exploration and mining operations and geoinformation systems, particularly when searching for oil and gas in the second half of 1980, when the high-quality images with the domestic satellite of the Kosmos series. Unfortunately, the lack of active competition on the enterprises in the planned economic system did not promote the development of a qualitatively new breakthrough satellite technology. Their production and use was costly. During the 90s, despite the relatively high profitability of enterprises in the resource sector compared to other sectors, could not be achieved due to the effective technical development and cost reduction in the manufacture of spacecraft and satellite navigation systems [1-7]. Given the high cost of designing and starting of equipment for the decade was increasing technical backwardness of the advanced samples, narrowed the application of the real sector of the country.

2. Theory and key questions
Consider the most relevant and successful examples of implementation of the GNSS at the largest enterprises in the resource sector in Russia and abroad. There are several the most important information satellite automated systems for the management of mining transportation complex among recent. In the United States navigation information system called "Dispatch", developed by Modular Mining Systems, was introduced for the quarry of Tiron. Due to its application performance for loading the transport sector increased on average by almost 11%. Lately a lot of companies was appeared in the domestic market which began to develop different types of automated information and navigation systems for the mining transportation complex. So, the KARIER Mine Management System was successfully implemented and oper-ates nearly 40 mining companies in Russia, Kazakhstan, Mongolia. The system used in large ore and coal mines, which are structures of holdings Mechel, Severstal, Erdenet, Sibuglemet. Regular data transmission is made on the basis of radio modems, using WI-FI connection in the whole area of mining high-speed data transmission, used in conjunction with existing systems high-precision satellite navigation is intended to solve all the necessary tasks for effective corrective of traffic. The systems allow to increase productivity by 15-20% and lead safe production and transportation of various mineral resources with heavy and difficult climatic conditions of the regions, decrease production costs and increase the total volume of extraction of mineral re-sources. For companies of ALROSA existing complex of geological and geophysical methods comes with the most high-precision equipment imported and domestic production. Satellite navigation systems for more than 15 years used by businesses, they are all geological and geophysical personnel engaged in the field work. Embedded and high-performance drilling equipment: drilling rigs LF-90 (Canada), the УБ -3,5 (Russia) - application of satellite
positioning drilling rigs at the quarry is performed to improve the accuracy of location of blast holes and more efficient use of explosives. Satellite positioning system using information about a current drilling depth, drilling rate, pressure in the hydraulic system allow to obtain information about the energy intensity of drilling rock in different points of the wells. The necessary information on-board computer of the drilling rig receives via radio from the dispatch center. The results of exploration work conducted previously in these areas, give confidence about their prospects and the possibility of discovery of new diamond deposits [8-13]. Given the projects and developments have the support of the Skolkovo Foundation, leading mining companies and of Rostekhnadzor. The main general trends and directions of development of modern domestic and foreign systems are as follows: 1) the use of high-speed and reliable wireless radio communication, allowing to transfer large volumes of telemetry and video data; 2) the use of high-precision satellite navigation that allows you to control the operation of the equipment with centimeter accuracy; 3) introduction of professional software for the automated dispatch of mining equipment. New energy theory of crisis management in the economy, the resource sector is based on the fundamental laws, which provide the necessary specificity and precision of parameter estimates. This complex system is characterized by the abundance of internal structural relationships and the interaction elements at the general structure level that will determine the most important regularities.

3. Research methodology and methods of analysis
The Integrated quality management system in the modern world represent the most important area of functioning and development of any production, to a great extent determine the competitiveness of the enterprise and prospects of its activities. The creation of new methods of technical and economic audit determines the need for and justification of the most common and objective criteria and evaluation indicators. To effectively manage this process, you need the ability to objectively predict and qualitative to determine the effectiveness of equipment at the design stage and run. Now more than ever, the most relevant to the mining complex of Russia and the world the problem of increasing the efficiency of mining production, the solution of which lies in global trends in the areas of new unconventional renewable energy sources and their adoption in resource-saving innovative technologies that, in addition to solutions to environmental problems, will allow to develop adjacent directions in the energy sector. Consider solving the problems of efficiency and quality of use of the equipment GNSS on the basis of qualitative calculations for the mining industry. While in orbit, the spacecraft is exposed to a rarefied plasma (space is not absolute vacuum, it does have charged particles that escape from the Sun). Over time, the surface of the satellite accumulate the charged particles, and the accumulation is unevenly. One of the factors limiting the reliable and continuous operation of the spacecraft (SC) is the electrification and associated electrostatic discharge (ESD). Electromagnetic interference (crosstalk) generated by ESD, causing failures in the on board avionics (OA) of the SC, and intense discharge currents can cause permanent damage to the components of the apparatus [14-19]. In 30% of cases of failure and further loss of the satellite associated with this effect. The main receptors of impulse noise from ESD are fragments of the onboard cable network (OCN) laid on the outer surface of the SC. You have to model the pattern of spreading of the currents on the surface of the SC. The calculation of the pattern of spreading of the currents on the SC design, in ESD by using structural elec-tro-physical model (SEM) takes the most time in the whole procedure of definition of the interference in the OCN SC. There are many numerical methods for calculations throughout the mod-el in practice in the software program (SP) for the calculation of the integrated circuits used with high accuracy and speed methods of PSpice, LTSpice, MicroCap. But the calculation of the equivalent electrical circuit (EEC) of large SC, using the most efficient LTSpice takes too much time (the experiment lasts for tens of hours, over 80, on a computer with a dual-core processor with a clock frequency of 2.4 GHz per core, the amount of RAM is 8 GB). For the calculation of large systems in the United States was developed software NanoSpice, the calculation produces 10-100 times faster than the methods used in these programs [20-25]. However, since the program is based on the mechanism of parallel computation, a necessary condition for NanoSpice is an expensive
supercomputer, consisting of about 120,000 processors. In addition, when calculating the pattern of current spreading on the surface of the SC there is no need to calculate the whole model. This is because significant area of the calculation, obtained empirically, is not significant (less than 1%). It is essential to the current near the place of discharge.

4. Analytical data processing and research

For the linear model of the EEC SC, which is a system of N linear ordinary differential equations (ODE) are discussed and justified the formal process of building its macro model (system of m << N equations), which contains explicitly a small number of variable circuit parameters (R, L, C) and reflecting the ratio "input - output". Obtained using the developed reduced computational schemes of the model (macro model) can be used as model elements of a higher level. The values of elements of the same type are the same. The experiments in the "Satellite-MIEM" show that the area in which the value of transient currents in the branches is not more than the value of 1-2 % of the value of ESR, represents 400 knots around the place of occurrence of ESD.

A value of transient currents in the branches, not exceeding the values in the 1-2 % of the value of ESR are considered to be minor due to the fact that electromagnetic interference from such transient currents exert a weak influence on the on-Board radio-electronic equipment of the SC - it is important to identify the pattern of flow currents in the local area. For the solution of large systems of differential equations in recent years began to develop the direction of the formation of simplified models of reduction, under which we understand the reduction of order of systems of equations. The main purpose of the reduction is the reduction of computational cost of the calculation model. A new approach of reduction of the linear model scheme based on the ex-clusion from the model of the subvectors containing the phase variables whose values do not exceed 1-2% of the value applied to the place of discharge current. The construction of the reduced computational scheme is based on the specificity of matrix models of electric SC. The model can be formed in the extended homogeneous coordinate basis (EHCB) and recorded in the form of a system of linear (1).

\[ C \frac{d}{dt} \bar{X}(t) + G \bar{X}(t) = \bar{Y}(t), \bar{X}(0) = \bar{X}_0, \]

Where is \( C, G \) a numeric matrix of order \( (n \times n) \), \( \bar{X}(t) \) is the vector of the sought phase variables (voltages in all nodes of the circuits and the currents flowing through the inductive elements) \( \bar{Y}(t) \) - vector of input signals.

You need with minimal time spent to perform the solution of system equations in time \( t^* \), to calculate a numeric vector \( \bar{X}(t^*) \).

The efficiency test results of the developed numerical methods to increase the amount of data in the calculations are presented in table 1.

**Table 1.** The result of the test numerical methods on a PC.

| The number of equations of the model | Analysis time models the explicit Euler method, s | Analysis time models the implicit Euler method, s | Analysis time model at reduced computational scheme, s |
|-------------------------------------|-----------------------------------------------|-----------------------------------------------|--------------------------------------------------|
| 100                                 | 0,11                                          | 0,16                                          | 0,012                                            |
| 500                                 | 1,3                                           | 118,9                                         | 0,83                                             |
| 1000                                | 4,44                                          | 811                                           | 13,26                                            |
| 1500                                | 9,6                                           | 4099                                          | 45,34                                            |
| 3000                                | 51,3                                          | 28697                                         | 387,5                                            |
The experimental results of the developed methods on a computer show that the reduced computational scheme is almost without loss of accuracy can carried out the same calculations, using known numerical methods, but with increased speed by orders of magnitude (m << N). Obtained using the developed reduced computational schemes of the model (macro model) can be used as elements in models of higher-level quality solutions for the improvement of the GNSS in the mining industry.

The offered way allows to lower expenses for hardware and the software by 10-15% and to considerably increase quality and possibilities of use of the satellite navigation system within technological processes of the mining enterprises.

Results of experiments are developed by the methods based on computer display in the way: calculation of the provided scheme practically without loss of accuracy will be carried out by the same calculations and with use of the known algorithms, but with the increased speed on orders [26-35]. Created on the basis of the generated reduced computing model it can be used as model elements for increase in level of quality of the solution of problems of improvement of the satellite navigation system organization for mining companies.

5. Conclusions

Innovative transport and space systems for effective use in the mining industry will be based on the creation and modernization of the following unmanned spacecraft and satellite technologies:

1. Clusters of small spacecraft (micro-, nano - and picosatellites) for Earth remote sensing, the deployment of broadband telecommunications systems, and traffic control vehicles.
2. Promising launch vehicles: reusable rocket-space system; space transportation system including the use of nuclear energy.
3. Aerospace aircraft to suborbital launch of small satellites.

The introduction of the deserted mining geo-technology would accelerate the development of innovative solutions in the field of high-precision satellite navigation GLONASS and software, as well as robotics and industrial electronics, which of course will lead to the strengthening of the scientific and engineering potential of Russia.

The general trends of development of innovative control systems are as follows: application of high-speed and high-steady wireless means of a radio communication which provide transfer of large volumes of a telemetric and video information; use of high-precision satellite navigation systems which allow to conduct positioning of the equipment with a centimetric accuracy; introduction of professional program platforms and means for the purpose of the automated scheduling of the mining-transport equipment. Now great interest is shown to creation and use of small spacecrafts — adequate replacement of big spacecrafts. It is explained by many advantages of microsatellites:

- Rather low price and also small time necessary for development and production of the microsatellite.
- Low price of start of the spacecraft. The carrier rocket, even an easy class, is capable to bring several microsatellites to an orbit.
- Conversion ballistic missiles, which, according to contracts, are destroyed by space launch with useful loading, are used to start.
- Easy spacecrafts can be removed in quality of a way cargo on the carrier rockets (CR) or in the transport ships delivering freights to long-term space stations.
- Reduction of risk of big financial losses at death of the microsatellite in case of accident of CR on start or at its unsuccessful removal into a working orbit.

The formed innovative transport and space complexes for the purpose of effective high-quality application for the mining industry will be based on introduction and modernization of a number of the satellite navigation system. Development of deserted intellectual geotechnologies will promote further active introduction of effective organizational technical solutions in the field of the GLONASS satellite navigation system, the automated program platforms, robotics and various electronics for increase in efficiency of course of productions.
6. References

[1] Vostrikov A V, Prokofyeva E N, Polesskiy S 2018 Design of onboard cable network of the spacecraft for the formation of geoinformation systems in 2018 (Moscow) Workshop on Electronic and Networking Technologies (MWENT) Proceedings (M) IEEE pp 1-5

[2] Forecast of scientific and technological development of the Russian Federation for the period until 2030 (approved. The government of the Russian Federation on 3 January 2014) URL http://www.garant.ru/products/ipo/prime/doc/70484380/#ixzz4AP1ZxHhy (26.02.2019)

[3] The Development Strategy of Information Technology Industry in the Russian Federation for 2014 - 2020 and the Prospect for 2025 URL http://government.ru/docs/8024/

[4] Yerulin Z M, Goncharenko S N Models for solving key problems of strategic development of uranium mines Gorny informatzionno-analiticheski byulleten' 2019 4 99-208 [In Russ]

[5] Belov A A, Olga G 2016 Andrianova. Anisotropy-based Analysis for Descriptor Systems with Norm-Bounded Parametric Uncertainties in Proceedings Of 2016 International Conference “Stability And Oscillations Of Nonlinear Control Systems” (Pyatnitskiy’s Conference) IEEE pp 1-4

[6] Prokofeva E N, Vostrikov A V, Shapovalenko G N, Alvarez A 2017 The development of effective geomonitoring for mining area with industrial review Eurasian Mining 2 pp 61-63

[7] "All about mining Extractive industry» URL http://industry-portal24.ru (5.04.2019)

[8] Expert report "12 solutions for new education» URL https://www.hse.ru/news/expertise/217884372.html (27.03.2019)

[9] The development of design education in engineering departments URL https://miem.hse.ru/project_office/project_list (17.03.2019)

[10] Zotov L, Frolova N, Shum C 2015 Gravity Changes over Russian River Basins from GRACE in Planetary Exploration and Science Recent Results and Advances Berlin Birkhauser/Springer

[11] Artamonov S 2016 Nonperiodic Modulus of Smoothness Corresponding to the Riesz Derivative Mathematical notes Vol 99 6 pp 928-931

[12] Aleskerov F T, Karabekyan D, Ivanov A, Yakuba V I 2018 Individual manipulability of majoritarian rules for one-dimensional preferences in Procedia Computer Science Vol 139 6th International Conference on Information Technology and Quantitative Management Elsevier pp 212-220

[13] Goncharenko S N, Duong L B, Petrov M V, Stoyanova I A 2014 Modeling of parameters of innovation water-protection measures on the basis of industrial-technological indices of coal mining at Vietnam enterprises Gorny Zhurnal 9 pp 143-146

[14] Potekhin I, Mischenko V, Mottaeva A and Zheltenkov A 2018 Evaluation of possibility to increasing sustainability of high-rise buildings through use university intellectual property E3S Web of Conferences D Safarik Y Tabunschikov and V Murgul (Eds.) P 03020 https://doi.org/10.1051/e3sconf/20183303020

[15] Gaydin A M 2009 From Geotechnology to geoesthetic Gorny Zhurnal 4 pp 72-76

[16] Ilin S A, Kovalenko V S, Pastikhin D V 2012 The overcoming of the open cut mining initial disadvantages experience and results Gorny Zhurnal 4 pp 25-32

[17] Mineral Commodity Summaries 2016 United States Geological Survey p 202 URL https://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf (10.03.2019)

[18] A Report on the State of the Canadian Mining Industry. Facts-and-Figures-2016 p 119 URL http://mining.ca/sites/default/files/documents/Facts-and-Figures-2016.pdf (09.03.2019)

[19] Ludden J 2015 BGS and the Comprehensive Spending Review URL http://britgeosurvey.blogspot.ru/2015/12/bgs-and-comprehensive-spending-review.html (17.03.2019).

[20] Samuel Fernández J 2007 Esteban Fernández and Alberto Álvarez Assessment of quality assurance models University institutional evaluation and academic achievement European University Association HOSTED BY SAPIENZA UNIVERSITÀ DI ROMA ITALY pp 60-67

[21] Ganitskiy V I, Dayanits D G, Vorobyev A G, Eyrikh V I 2011 About development of
innovation activity and its staffing in the mining industry GornyiZhurnal 12 pp 27-30
[22] Aleskerov F, Ivanov A, Karabekyan D, Yakuba V 2015 "Manipulability of Aggregation Procedures in Impartial Anonymous Culture" Procedia Computer Science Vol 55 pp 1250–1257
[23] Vartanov A Z, Petrov I V, Kobyakov A A, Romanov S M, Fedash A V 2015 Ecological and economic aspects of the transition of the mining enterprises on the principles of best available technologies Gorny informatziomno-analiticheskiy byulleten i pp 511-521
[24] Goncharenko S N, Kobyakov A A, Petrov I V, Stoyanov I A 2012 Economic-mathematical modeling of the distribution of the value of the cost of the preservation and restoration of the environment in the areas of mass closure of coal mines Ecological and economic problems of the mining industry and development of fuel and energy complex of Russia Preprint Gorny informatziomno-analiticheskiy byulleten pp 20–25
[25] Kaplunov D R, Rylnikova M V, Radchenko D N 2015 Utilization of renewable energy sources in hard mineral mining Journal of Mining Science 1 pp 111-117
[26] Korinek J and Ramdoo I 2017 Local content policies in mineral-exporting countries OECD Trade Policy Papers No 209 OECD Publishing Paris http://dx.doi.org/10.1787/4b9b2617-en (27.03.2019)
[27] Mining Digital Report 2017 PwC School of Mines URL http://www.pwc.com (09.03.2019)
[28] Mining for efficiency reports PwC School of Mines URL http://www.pwc.com (01.04.2019)
[29] Temkin I, Deryabin S, Konov I 2017 Soft computing models in an intelligent open-pit mines transport control system Procedia Computer Science Vol 120
[30] Temkin I O 2018 Do Chi Thanh Agabubaev A T Some algorithms of functioning analytical platform in the control system of ventilation methane abundant mine Mining information-analytical Bulletin scientific and technical journal 16 pp 3-15
[31] Temkin I O, Klebanov D A, Deryabin S A, Konov I S 2018 Method of determining the state of the haul road career in the management of the interaction between robotic elements of the mining transportation complex Mining journal 1 pp 78-82
[32] Prokofeva E N, Vostrikov A V, Fernandez E, Borisov N 2017 Navigation satellite systems as the audit foundation for mining companies Eurasian Mining 1 pp 30-32
[33] Konik P V, Prokofeva E N, Vostrikov A V, Goncharenko S N 2018 Prospects for the development of engineering projects and digital learning technologies Step into the future artificial intelligence and digital economy Revolution in management a new digital economy or a new world of machines [Text] proceedings of the II International scientific forum Issue 3 State University of management (Moscow Publishing house GUU) pp 463 – 466
[34] Alvarez A, Fernandez E, Prokofeva E N, Vostrikov A V 2019 The building of effective systems of training and development for mining engineers with the basis of digital technologies Eurasian Mining 1 pp 49–52

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