DEVELOPMENT OF SCIENTIFIC FOUNDATIONS OF RESOURCE-SAVING TECHNOLOGIES OF MINERAL MINING AND PROCESSING

Multi-authored monograph

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The multi-authored monograph deals with the issue of creating substantiated resource-saving technologies of ore and nonmetallic mineral mining.
The book targets mining scholars, practitioners, lecturers, postgraduates and mining students.

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PREFACE

We are glad to present the multi-authored monograph "Development of scientific foundations of resource-saving technologies of mineral mining and processing".

Ukraine is one of the leading countries in terms of mineral mining and processing. Great amounts of extracted minerals call for an efficient and complex approach to their mining and processing. This approach based on extensive introduction of energy- and resource-saving technologies will allow maintaining the balance of efficient resource exploitation without reducing mineral mining rates.

The multi-authored monograph is aimed at creating scientifically substantiated resource-saving technologies of mining and processing ore and nonmetallic mineral resources.

The monograph represents articles analyzing approaches to selecting technological and technical solutions for complex mineral mining.

The multi-authored monograph targets both mining researchers and young people mastering mining specialities at higher educational institutions.

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SCIENTIFIC BASIS OF ORGANIZATION AND MODELING OF MINING PRODUCTION AS A COMPLEX ECOLOGICAL AND ECONOMIC SYSTEM

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Abstract

A difficult situation has currently developed in the main mining regions of Ukraine which is caused by extremely heavy load on the environment from the development of mineral deposits up to the level of ecological disaster. In these conditions, it becomes especially urgent to create the new approaches to such mining developments, which should ensure both minimum environmental damage and increase in the economic efficiency of production, which is the subject of research carried out by the authors. In this work, on the basis of the methodology of integrated approach to economy and environmental factor of mining production, the scientific foundations for the organization of cost-effective development with maximum use of the economic potential of natural resources, which ensures minimum environmental damage, were developed by the authors. The conclusions on the work concentrate the conceptual foundations of such approach as well as the principles, conditions and opportunities for its implementation with the current level of equipment, technology and methods of organizing the mining production.

Introduction

Ukraine is one of the largest mining countries of the world. On a production capacity and scale of mountain works its mining complex is included in four the largest among countries with the developed mining industry. This complex is conducting in the structure of industry of Ukraine and its economy, by submitting one of the most large sources of the financial entering the state budget.

However lately the basic mining regions of Ukraine ran into a serious problem, consisting in that over the protracted intensive development of deposits of minerals brought to considerable violations of the state of natural environment in by Donetsk, Pridneprovsk, Kirovograd, L'vov-Volynsk coal pools, Krivorozhsk iron-ore pool, Nikopol-marganets pool. To beginning 2000 years these violations attained such scales, that the indicated regions appeared on verge of ecological catastrophe.

The followings displays have such violations: scale changes of the geomechanical state of bowels of the earth, which result in the mass moving and bringing down of surface, technogenuous earthquakes, mountain-rock shots; that brings violation over of the hidrogeological state of bowels of the earth, causing the uncontrolled moving of considerable volumes of underground waters, to drainage of large areas of earthly surface, water-flooding of considerable territories, solinization and sources of drinkable water-supply; violation of chemical composition of air as a result of the troop landings of toxic and chemically active gases from work of equipment, explosive works and gas-outcoming of breeds, broken mountain works; change of chemical composition of soils as a result of their contamination the pulverulent particles of useful minerals and in passing extractive mountain breeds, which have cardinally different chemical composition from composition of soil.

All of these processes sharply put the problem of necessity of urgent decline of the techogenuous loading from activity of mining enterprises on an environment, that decisions of problem of ecological safety of mining production and his enterprises.

1. Basic complications of decision of ecologically-economical problem

The decision of foregoing problem restrains a temper the followings factors: by absence of the scientifically grounded going near development, planning and introduction of technology and techniques which provide the decline of the negative influencing of mining production on an environment; by the insignificant volume of technological and technical decisions which would provide ecological safety and economic effective development of deposits simultaneously; by absence of the scientifically grounded directions of development of mining enterprises in the conditions of intensification of production, complication of geotechnical and economic their operating conditions; by the low rates of conducting of researches of system-economic aspects ecologically safe functioning of mining enterprises.

Researches of row of organizations are devoted the decision of problems of ecologisation of mining complexes of Ukraine. The most meaningful fundamental results are got the group of scientists of such universities of Ukraine, as the Krivorozhsk national university, Dnipro National mining university East-Ukrainian national university the name of V. Dal, Donetsk national technical university and. During the last researches were 10 years conducted and the complex of developments of conceptually-theoretical and applied character is executed for the decision of this problem. These developments are taken in the general problem-oriented work «Development and introduction of high-effective technologies of ecologically defence orientation of production complexes of Ukraine» which includes developments on such directions: conceptual theoretical bases of the ecologically-economscfl going near providing and organization of ecologically defence mining production; analytical researches, laboratory and industrial experiments on the different aspects of planning of technological processes and mountain equipment for perfection of production processes in sending of decline of their harmful impact environmental and providing of economic efficiency of development; scientific grounded methods of calculation of parameters and methods of management the processes of guard of bowels of the earth, earthly surface, water environment and atmosphere at development of deposits; scientific bases of development of system-economic aspects of the complex use of natural resources, increase of ecological safety of mining production, organization of production and management enterprises; technological decisions on realization of development of deposits of minerals with the use of facilities, removing the dangerous production troop landings ecologically; scientific bases of processes of cleaning and disinfecting of mine waters; to recommendation on determination of ways of further improvement of ecologically-economical activity of mining enterprises.

Theoretical positions of this work served basis for development of new technologies and modernization of activity of mining enterprises which do not have analogues in world practice and oriented to the decline of the negative influencing of mining production on the state of natural environment with the simultaneous providing of high economic efficiency of mining. The substantive conceptual provisions of this work are set forth below.

2. Features of innovation-investment activity in area of mining production, as basis of introduction of ecologically defence technologies

One of major terms of providing ecologically of the safe and economic effective functioning of mining production is the grounded innovation-investment policy of enterprise, taking into account influence of ecological factor on parameters and results of development of minerals [6, 8]. Absence of account of this factor during organization, planning, planning and management of mining operations can result in serious negative economic and social consequences. The exact estimation of character of this factor and his displays in the concrete terms of development of deposits allows correctly to forecast all of its consequences (which can have catastrophic displays), plan, organize and develop economic activity of enterprises, providing high economic results at minimum negative influence on a natural environment.

Actuality of account of ecological factor in activity of mining enterprises especially increases in market economic conditions in connection with the necessity of decision of contradictions of economic task on a joint «nature-market». This task arises up in connection with natural incuriosity of business enterprises in the investment of financial means in nature protection measures, for lack of line arrived, to prolonngation in time of offensive of responsibility for the inflicted ecological harm, lacks of coincidence of interests of enterprises and recipients (population, other enterprises, state). The special attention is required by the questions of management the processes of technological innovations, as the last not only determine affecting of production natural environment, but indissolubly related to control of inventories of natural resources and their rational use (booty without losses and decline of quality), that determines the economic results of development straight.

Market relations stipulate the necessity of consideration of ecological problems of mining production from point of ecologically-economical approach. It is special underlined in conception of steady ecologically-economical development, formulated in the «Global program of actions - Notice on 21th age», accepted at conference «environment and development», conducted under an aegis UNO (Rio de Janeiro, 1992). Positions of this program are required by introductions of the system of estimation of activity of industrial enterprises from point of prevention of possible negative ecological consequences from their functioning. Thus, grounded, that achievement of the put purpose is impossible a way only technological development, for this purpose it is necessary to subordinate it achievement all of innovative activity, because ecological problems engulf all of complex of technological, technical, organizational, scientific, economic aspects of production. Only by the complex going near his innovative development it is possible to attain balance as between society, production and natural environment.

To the present tense within the framework of modern innovative strategy in industry folded two on principle different going near the decision of its ecologically-economical problems. The first direction is direction of investment of financial means in «de bene esse clean technologies», when simultaneously with a basic production nature protection measures are conducted (for example, building of cleansing buildings, research ecologically of safe places of storehousing of wastes, application of the systems of desinfection (recuperation) of wastes, special measures of defence of environment from powerful production factors (shock waves from industrial explosions, noise affecting environment from working mightily technological equipment, radiation, electromagnetic radiation etc.). However, at such approach considerably financial production inputs increase and unit of mining enterprises cost. In addition, as world practice showed, limit of harmful influence of production on an environment by a way only isolations of production processes, does not result in the substantial improvement of the state of environment and cardinal decision of this problem, braking of negative processes is here arrived at only. Another negative aspect of such approach is that in certain terms financial expenses on nature protection measures can appear higher than expenses on liquidation of consequences of harmful influence on an environment and these measures will be economic unjustified although ecological harm will remain high.

More justified from the economic point of view is other going near the decision of ecologically-economical problem, namely is the ecologically oriented restructuring of industries of industry of exploiting natural resources. Under restructuring the change of character and methods of production-economics activity of enterprises is understood. The purpose of such restructuring is: minimization of volumes of engaging in exploitation of natural resources (supplies of deposits) at the receipt of necessary amount of commodity products; reduction of volumes of wastes at the production of basic goods for чет of the most complete extraction of useful component from the obtained source of raw materials; application of technologies, eliminating harmful influences on an environment at implementation of technological processes (for example, passing to the biological kinds of fuel, nonexplosion separation of useful mineral etc.), in case formation of wastes the last must in good time join in the single production chain of their use as sources of raw materials for other productions.

Innovative activity of enterprises in the conditions of restructuring must execute the followings functions: acceleration of structurally-technological alteration of production; decline of ecological risks at introduction of innovations; increase of level of skilled and scientific and technical potential; providing of co-operation of science, production and finansial-credit sphere. Taking into account the last function evidently, that «ecologisation» process of structurally-technological alteration of enterprises must be examined in indissoluble connection with innovative and investment activity.

It is necessary to mark that besides realization of the ecologically oriented restructuring of basic production of industrial enterprises, a large value is acquired by reformation and development of market mechanisms of ecologisation, namely creation of favourable organizationally-economic terms for an innovative enterprise in area of ecologically safe production. From all of types of innovative activity their special kind was already selected in this direction – ecologically clean technologies. With every year amount of users ecologically grows clean products in the whole world, including in Ukraine. A basic task here consists of creation of terms, when enterprises, realizing such technologies, will be able to get an economic effect from their activity commensurable with the sizes of capital financial investments in a production.

3. An economically-lawful mechanism of providing of activity is in ecologically defence activity of mining enterprises

A large value in ecologically-economical direction has legal base. Due to realization of effective economically-lawful mechanisms of management an economy such terms of production activity of enterprises, at which to the managing subjects is economic advantageous to observe a nature protection legislative base, reduce the level of harmful influence on a natural environment, must be created, to warn (but not to liquidate) his appearances, search the methods of rationalization of production due to the use of new resources-saving and ecologically defence technologies of mining, and also technologies of processing of its by-products.

The economic mechanism of ecological management, certain the base laws of «About to the guard of natural environment, operates in Ukraine». Due to the economic instruments of this law bases of requiring payment natureusing and economic tool are worked comes forward the unique mean, allowing to provide the receipt of financial resources, necessary for the removal of harmful influence on a natural environment. However, the substantial lacks of domestic economic mechanism of ecological management are the followings: he is unable to interest commodity producers in conducting of nature protection measures due to the personal money funds; not corresponds with other economic indicators and levers of economic activity; it is not enough operatively and effectively reacts on the dynamics of economic and ecological processes in the state.

Claim of the economic going near a management natureusing in the state predetermines the necessity of scientific development and introduction in practice of reliable economically-lawful mechanisms of making healthy of natural environment at all levels of management. It is thus expedient to carry out introduction of economic mechanism of adjusting of natureusing not only by administrative instruments, but also «economic dictate», that creations of such terms for production activity, at which to the managing subjects it was legislatively regulated and achievement of ecological aims is economic advantageous in all of economically-lawful and production sphere of his activity. Claim of the economic going near a management natureusing and guard of environment does not mean the waiver of administration-lawful methods of management. Government (administrative) control must be in an equilibrium with the methods of the market (economic) adjusting. Simultaneous realization of economic measures, strengthening of state control and adjusting, can stimulate enterprises to inculcate new ecologically defence technologies, instrumental in the cutback of spending of facilities of state and local budgets due to setting to of load of ecological responsibility on enterprises, to the economy expense of resources (because of introduction of the reserved technological processes), change of orientation of investing on ecological aims, to the improvement of the administrative ecological adjusting.

Presently positive tendencies, directed on introduction of conclusions of conception of steady ecologically-economical development, register in the industrial regions of Ukraine. It means that the process of gradual building (integrations) of ecological factor began in the system of modern production, and also in the economically-lawful mechanism of functioning of market. An ecological enterprise develops as a result of it, and, consequently, the market of ecological business is formed. That the sphere of ecological technologies becomes the object of profitable commercial activity. As a result of it there is a certain infrastructure, including a few independent directions business of activity in area of mining production, main from which followings: creation ecologically of safe and resource-saving technique and technologies of realization of development, providing a high performance and economic efficiency of implementation of technological processes at minimum negative influence on a natural environment; utilization of wastes of processing of obtained useful minerals (wastes of production) as sources of raw materials for other productions; use of the materials got in passing; production of devices for control of the state of environment; ecological reproduction.

4. Direction of utilization of wastes of mining production and his economic value

It is necessary to mark that mining industry of Ukraine and its enterprise carry monoproductive character (booty of one concrete mineral at development of deposit) mainly, which the far of hard, liquid, gaseous and aerosol wastes appears at. That mastering of deposits carries complex character neither on the use of the obtained source of raw materials nor on the use of the materials got in passing. In accordance with conception of steady development its converting must one of actual directions economic activity of enterprises of this production become into multifood.

In Ukraine perspective and financial viability of the use of different materials, got during realization of basic production is more than twenty years probed already, and developed row of concrete recommendations on development of this direction. In theory, experimentally and experimental a way set and grounded possibility of the use of such products as raw material both for an own consumption mining enterprises and for the needs of national economy. Speech goes about the use: wastes of production – for the book-mark of the produced space of mines (sands, clays, rubble stone), for the production of build materials (agloporeet, ceramzeet, cuts, clays) and ceramic wares, in travelling and hydrotechnical building, as a fertilizer in agriculture; liquid wastes (mine waters) – as a source of economic and drinkable water-supply, in irrigational aims, as a source of lowpotential warmth and other.; gaseous wastes – as a fuel, electric power, priming of cars, for the production of chemical goods.

Results of theoretical, experimental researches and experimental tests, showed that a multifood production at the complex mastering of deposits was the substantial factor of decline of basic unit of mining production cost, because the additional types of commodity sources of raw materials turn out in this case. Due to this factor the prime price of basic commodity raw material goes down on 10-20% and more. Pre-condition of drawing on this reserve is a presence on Ukraine from the developed industrial infrastructure of potential users of passing products and their participating in investing of projects of utilization of the materials got in passing from a mining production.

Development of industry of processing and utilization of wastes on modern technical and technological basis in combination with the innovative model of steady development allows complex to decide the ecological, economic and social questions of alteration of economic mechanism of mining industry. To the most essential constituents of this aspect behave: engaging of the second raw material in an economic turn; development of the specialized powers on processing of wastes; issue of the special equipment for utilization of wastes; production of new types of products (build materials, fuel bricks, methane and other); introduction of control the system by utilization of wastes within the framework of created technoparks and innovative-technological centers; increase of technological level of basic production of mining enterprises due to introduction of front-rank scienceful technologies; conducting of the special research works on the having a special purpose programs; creation of new workplaces. From the resulted list of questions evidently, that in realization of directions innovative strategy of development of mining industry an important role belongs to science. Only with its help the technical retooling of active production vehicle of enterprises and transformation of industry can be continued in polyproductional.

An important form, specifying practical development of industry of processing of wastes, is organization of enterprises of small business (in composition mining enterprises and combines or functionings independently). By priority direction of development industry of processing of wastes, infrastructures of its service on the basis of progressive scienceful technologies there is creation of technological parks (techoparks).

5. Role of state administration in the decision of problem of economic tasks ecologically to safe activity of mining enterprises

The acceleration of practical realization of measures on creation of polyproduction requires development of legislatively-normative base and mechanism of government control of natureusing with addition or making alteration in a code about the bowels of the earth, Mountain law, law of Ukraine on «wastes» (in part of limitation or prohibition of booty of resources from the bowels of the earth, if in this region there are the second resources which suit to raw material).

Organization of account and effective state administration the rational use of natural resources, in economic activity it can engaging of wastes of mining production be well-to-do by realization of the followings measures: by development of the program of the use of natural resources which are obtained simultaneously and in passing with basic mineral resources; drafting of the State cadastre of the second mineral resources; by acceptance of the program of development of technologies of processing of wastes of production and mineral materials obtained in passing. The decision of the indicated problem does not have technological limitations and depends only on the volumes of financing.

The decision of most problems which a mountain enterprise runs into in a great deal depends on a public policy in this sphere and efficiency of functioning of instruments of economic mechanism of state administration in the field of using the bowels of the earth, and similarly from the relation state and mining enterprises. On scheme 1 the structure of connections and relations which must be realized for providing of efficiency of mechanisms of state administration in area of using the bowels of the earth and realization of the ecologically defence functioning of mining enterprises is presented. For the decision of the indicated problem the use of the followings organizationally-economic instruments is needed: development of functions of audit; risk estimation (financial and ecological); guarantees from the side of the state for an investor; tax deductions for a mountain enterprise; regional coefficients.

We will consider each of these instruments more in detail. Necessary and expedient is introduction of mechanism of audit on the first stage of process of preparation to delivery of license to realization of activity in area of development of deposits of minerals. It is thus necessary to conduct the followings types of public accountant estimation: geological, geophysical, hidrogeologics study of territories and determination of their prospects for a search and secret service of deposits of minerals; a geologically-economical audit is an overvalue of present fund of minerals on economic and ecological criteria and monitoring of raw mineral-material base; an ecological audit is research of the state of geological environment and development of dangerous exogenous geological processes. On the basis of results of audit the feasability study of development and exploitation of deposits must be executed with the purpose of determination of their investment attractiveness.

Feasability study – allows to define the amount of monies on geological works which must it will be be expended on realization of development. Information on commercial profitability of using the bowels of the earth must become a base for determination of level of financial risk. It will allow the state to indemnify itself against economic losses in the process of grant of privileges a mountain enterprise.

The level of ecological risk also needs to be taken into account in the process of acceptance of administrative decisions. In Ukraine yet finally the effective methods of calculation of level of ecological risk are not developed and, accordingly, the mechanism of ecological insurance does not work. This direction is examined as one of effective organizationally-economic instruments in the future. The conclusions of audit and technically-economical estimation, except for the state, also will be useful: to the investor for a decision-making in relation to an investment facilities in creation and development of mountain enterprise, and to finansial-credit establishment for the ground of expedience of delivery of credits for realization of projects on creation of enterprise and providing of his production activity.

After treatment of the got results and information as evaluated by the level of risk, owe its systematization is conducted and formed regional, and also national informative systems in the field of using the bowels of the earth.

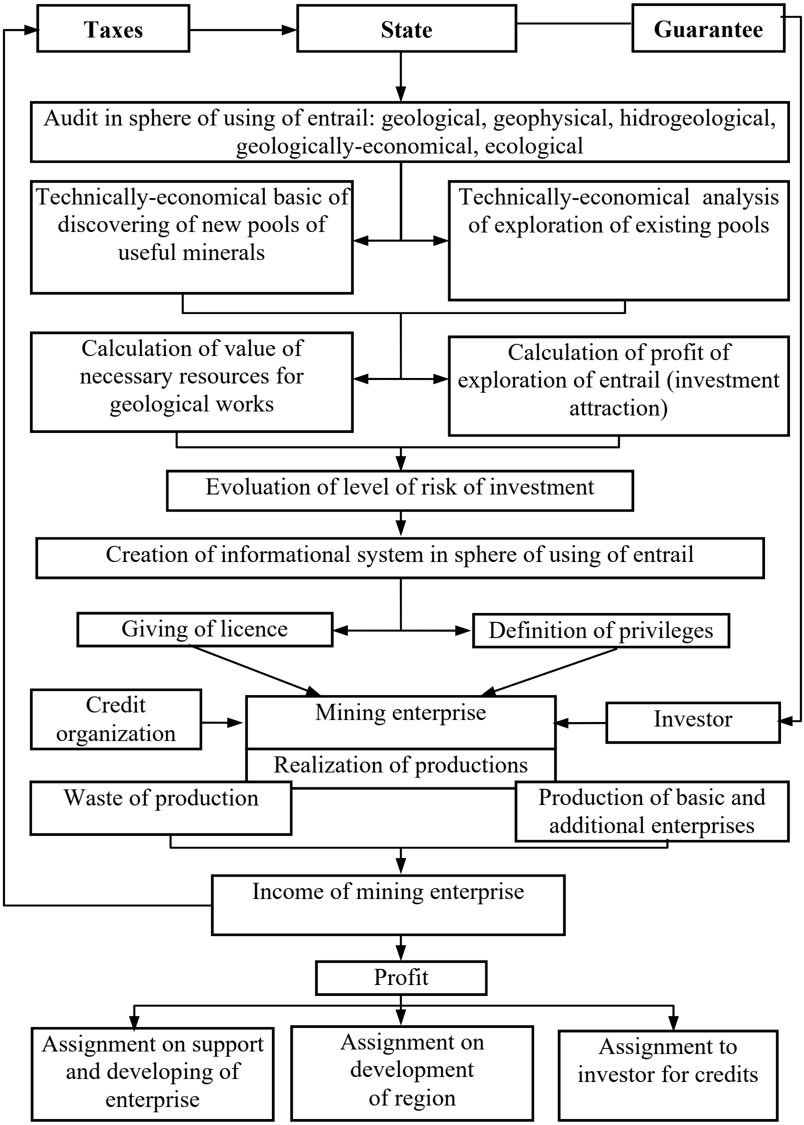

Fig. 1. Structure of connections "State – Mining enterprise"

The public specialized organs of power give out a license to mountain works and determine a requirement in privileges for a separate enterprise taking into account geological, hidrogeological, ecological, economic terms.

6. Basic indexes, reflecting efficiency of ecologically-economical measures

Coming from described higher, there is a necessity of quantitative ecologically-economical estimation of nature protection activity in area of mining production and his efficiency. Such estimation can way of life carried out on the basis of comparison of economic results of production with the volumes of consumable natural resources for realization of production and by the level of the tecnogenuous loading on an environment from his activity. As a result of it the change of having a special purpose options and estimation of innovative strategy of development of production is required, when taking into account the traditional estimation of economic efficiency of innovations the necessary and priority is become by consideration of criterion of ecological efficiency.

Descriptions of ecologically-economical activity of mining enterprises can way of life described plenty of indexes and parameters. However there is a row of indexes which are most representative and in the most complete measure describe a situation in the decision of this problem. We will consider such indexes.

Naturally-resource potential *of Pr*, characterized the volume of gross domestic product (*GDP*) in a value term, which can be got as a result of engaging in development of concrete deposit (or his parts) taking into account expenses, necessary on realization of development and realization of nature protection measures. Position at which nature protection measures provide the receipt of such product is thus taken into account (for example, due to utilization of wastes of production)

$$P_r = Q_m \cdot C_m - S_m + Q_p C_p \qquad (1)$$

where Q_m – volume of commodity product, got as a result of working off the supply of deposit or his part; C_m – price of commodity product; S_m – sum of financial production inputs commodity blown through; Q_p – volume of commodity product, got as a result of nature protection measures; C_p – price of commodity product, got as a result of nature protection measures.

Naturecapacity of economy – characterizes a type and level of ecologically-economical development. Select two levels of indexes of natureful: macrolevel (all of economy) and productive (industry).

On a macrolevel under naturecapacity l understand the expenses of natural resources (or resource *of N*) on unit *of GDP V*, national income et cetera Measuring of these indexes can be made both in a cost form and by a naturally-cost.

$$l = N / V \quad (2)$$

At of (productive) a particular branch level indexes are determined the expenses of natural resource calculating on unit of eventual products *of Vp*, made on the basis of this resource:

$$l = N / V_p \quad (3)$$

Natural resourcereturn O is a size, reverse l

$$O = V / N \quad (4)$$

Among indexes, included in a formula (2), there is GDP which is traditionally utillized in a world economy for the estimation of economic development of countries. He is expected by a method by the sets of compatible national accounts. The tendency of basic orientation is presently noticed at the calculations of results of functioning of economy only on GDP. However, from data of UNO and World bank this index does not reflect veritable economic realities, as does not take into account the overall cost of harm from depletion of natural resources and contamination of environment (ecological aspect). Investigation of the first failing is that activity, directed on liquidation of ecological harm, is taken into account in GDP as contribution to the increase of welfare of country. For example, at the receipt of wood the forest is destroyed. Facilities, rescued from the sale of wood as an income, joins in GDP, but harm, inflicted nature by elimination of the forest, is not taken into account here, harm to the air pool (to the cleanness of air, amount of oxygen), soil waters, биоразнообразию and other As a result of it there is a paradoxical situation, when high GDP does not yet mean that a country develops steadily, because a great deal depends on that, due to what factors arrived at his high value. Consequently, adjustment of method of calculation of this index is needed. This conclusion is supported in conception of steady development, i.e. for determination of net gross product (NGP) it is necessary to subtract from GDP a sum ecological harm (EH) and charges on renewal of natural environment (P)

$$NGP = GDP - EH - P \qquad (5)$$

In the light of written, the World bank in order of experiment already began to assess the economic situation of countries on a new method by an index «index of veritable economies». Calculations, executed on a new method, show that many countries, oriented to the booty and export of raw material does not get the positive increase of economy.

The observance of the criteria resulted higher is closely related to unsolved while, but by an important problem for the vital functions of society – by the problem of resource-saving. This problem is the result of the economic state of affairs in connection with narrow-mindedness of natural resources. Term «resource-saving» underlines the base idea of evolutional economy, formulating a new paradigm in control the system by an enterprise, namely idea of minimization of the use of natural resources as an instrument of increase of efficiency of control the system by an enterprise. Its realization is examined as one of basic modern directions intensification of production.

The most evident index in regard to resourceusing is an index of rationality of the use of resources

$$K_n = 100\% \cdot Q_h / Q_n , \qquad (6)$$

where Q_h –is an amount of resources, utillized a production; Q_n – is an amount of resources, withdrawn from a natural environment.

The special case of this index is a «index of plenitude of the use of matter» within the limits of region which is attitude of volume of the made products toward the volume of the consumed matter for certain period of time.

As a summarizing index utillize a coefficient, showing the stake of extraction of useful components from the certain amount of the obtained raw material in a value term

$$K_k = (C_n / C_c) \cdot 100\% \qquad (7)$$

where C_n – is an output, actually made from mineral raw material value; C_s – is a total value of components in raw material, taken for a base.

Besides the considered two indexes of the use of natural resources, in the conditions of mining industry additional coefficients are used on the separate types of wastes, on the value of which the economic results of mining production depend straight. By basic indexes describing position with wastes are: on hard wastes is a coefficient of nonwaste production on the breed *of Kp*, specific rock yield taking into account its use *of Kpi*, coefficient, characterizing correlation broken and recultivated earths γ

$$K_p = q_1 + \frac{q_2}{Q} 100\% , \tag{8}$$

$$K_{pi} = Q - \frac{q_1 - q_2}{D} , \tag{9}$$

$$\gamma = S_n / S_{ot} , \tag{10}$$

where q_1 – amount of breed, utillized as book-mark material or for other aims; q_2 – amount of breed, utillized as raw material for making of build materials, for filing up of areas of bringing down etc; Q – general amount of breed, appearing as a result of conduct of mountain works; D – annual booty of useful mineral; S_n – area of earths, recultivated and passed for the use agricultural or other to organizations; S_{ot} – area of destructured (subject of recultivation) earths

On liquid wastes is a coefficient of nonwaste production on sewages *of Kv*, level of the use of the waters taken away in passing on the production needs *of Kvi*, degree of cleanness of the thrown down sewages $\gamma_в$

$$K_в = \frac{g_1 + g_2 + g_3 + Q_1}{Q_o} \tag{11}$$

$$K_{вi} = (g_в / W) \cdot 100\% \tag{12}$$

$$\gamma_в = P / PAH \tag{13}$$

where g_1 – volume of the water taken away in passing for own production needs; g_2 – volume of water, utillized for the needs of agricultural enterprises; g_3 – volume of water, utillized for the needs of contiguous enterprises; Q_1 – volume of upcast of the waters taken away in passing, proper the concerted norms of quality (volume of the normatively cleared waters); Q_0 – general volume of the water taken away in passing at a booty; W – general volume of the utillized water on production needs; P – actual maintenance accordingly of the weighed matters; PAH – the possible amount of harmful matters is maximum in water (accepted in accordance with the rules of guard of superficial waters from contamination sewages).

On the dust-gas troop landings is a coefficient of nonwaste of production on the troop landings in the atmosphere *of Kv*, degree of cleanness of the troop landings in an atmosphere γ_i

$$K_v = (M_y / M_o) \cdot 100\% \quad (14)$$

$$\gamma_i = C_{mi} / PAH \quad (15)$$

where M_y – total amount of the utilized harmful matters; M_0 – is a general amount of outgoing (appearing) harmful matters; C_{mi} – maximal amount of matter of concrete kind in atmospheric air.

The possible amount of harmful matter is maximum PAH (according to sanitary norms)

A coefficient of nonwaste in a general view is attitude of mass of the utilized wastes toward mass selected in the process of production

$$K = 0{,}33 \cdot \left(K_p + K_в + K_v\right) \quad (16)$$

The resulted indexes reflect the degree of ecologically-economical efficiency of activity in area of defence of environment. However yet created the systems of such estimation which allowed most full and comprehensively to reflect all of factors and features of influencing exactly of mining production on an environment are, ecologically-economical consequences from this influencing, and also concrete measures on protecting of environment from such influencing.

Conclusions

Arising up lately in the basic mining regions of Ukraine the serious problem of the extraordinarily high technogenuous loading on a natural environment demanded decision of a number of tasks, directed on providing of possibility of the further large-scale and economic effective mining at the maximal decline of display of harmful for ecology production factors.

The analysis of terms which resulted in such consequences, and also economic and technological feasibilities which are possessed by the scientifically-industrial complex of Ukraine, executed authors showed that this problem can be decided. Its decision must be carried out on the basis of the new going near methods and organization of functioning of mining industry and its enterprises.

The successful decision of this problem is possible at development of measures on such directions:

– substantial expansion of innovation-investment activity of mining industry in the direction of investment of facilities in development and creation of innovative environmentally clean technologies of development of deposits and booty of mineral resources;

– wide introduction ecologically of clean technologies due to a transition in mining industry from a policy simply protecting of environment from the harmful influencing of production, to the policy of priority of technologies which eliminate or maximally reduce the level of influence on the environment of production-technological factors;

– creation the state of legislatively-legal base of activity of mining , stimulant their personal interest in an ecologically safe production by combination of normative legislative bases and economic stimuli as tax deductions, policy of fines and so on;

– stimulation of the complex mastering of deposits with providing of profitability from a multiproductive production due to engaging in processing of wastes of mining production, industrial use of the materials got in passing both for the internal use and for realization external users;

– creation of the single system of estimation of ecologically-economical activity of mining enterprises, allowing correctly setting the level of ecologically-economical efficiency of their functioning.

Complication and many-sided nature ecologically-economical problems so high, what only during complex realization of measures on all of the indicated directions realization ecologically of safe mining production is possible in activity of mining industry and its enterprises.

DETERMINATION AND RESEARCH OF NORMS OF THE FERROUS QUARTZITES PREPARED TO BOOTY

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Abstract

Investigational provision of every extractive power-shovel the industrially-balance supplies prepared to the booty with the different degree of preparedness to the booty and quarry on the whole depends on a time domain between loosening of array of ferrous quartzite's and than anymore this time domain, the greater material well-being of every power-shovel removed, indignant and by other industrially-balance supplies prepared to the booty. At the same time domain between loosening of array of ferrous quartzites in coalfaces a time domain between the mass loosening can be anything. It is well-proven that effective work of quarry in the case when time domains between the mass loosening of array of balance-industrial supplies and loosening of array of ferrous quartzite's in coalfaces gather. Reasonably, that an optimal time domain between the mass loosening of array of balance-industrial supplies in iron-ore careers is in limits from two to three weeks and average of transitional removed from the array of ready to the booty of balance-industrial supplies is necessary to be increased on the coefficient of transporting.

The offered methodology of setting of norms of the balance-industrial supplies prepared to the booty is approved on the careers of Kryvyi Rih, and the methodology of setting of norms of preparedness of the balance-industrial supplies prepared to the booty, worked out for operating ore-mining enterprises modernized and adjusted to the use on the stage of planning. By an experience way the set values to the coefficient of reserve of extractive units, time domain between loosening of array of ferrous quartzite's in an extractive coalface accordingly in months and in changes and at presence of in the career of the motor-car and railway transporting of iron-ore mass from coalfaces for different time domains the got dependences for the calculations of norms ready to the booty of balance-industrial supplies.

Considered hypothesis about connection between middle for inside and for inters laughter dispersions of content of quality indexes of the iron related to magnetite, the sizes of that from different parties characterize changeability of content of quality indexes of minerals in the bowels of the earth and in iron ore mass, tested in the presence of correlation between these indexes. The brought dependences over between the sizes of time

domain between the mass loosening and productivity of extractive units are lines, use that for time domains between the mass loosening of array of ferrous quartzite's that equal according to one, two, three and to four weeks, as a function of the productivity of quarry on mountain mass (in default of breeds rocky opening).

Introduction. For trouble-free and productive work of every extractive unit at the booty of ferrous quartzites by an open method, it is necessary, that certain accordance stuck to between the different project technological types of mountain works. Planning of development of mountain works in the process of exploitation of balance-industrial supplies of deposit, bed, ore body or areas of array of hard minerals is the important stage in the decision of questions of technology of mountain production that provides plenitude of mastering of balance supplies of bowels of the earth [1].

At the annual planning of development of mountain works go into detail and specify perspective plans, and also decide concrete technological questions: establishment of volumes of the ore preparation, threaded and works taking into account norms on the degree of preparedness of the prepared and ready to the booty balance-industrial supplies exposed,, and also task on the volume of commodity products; set research constructed, research and other works, what booties of balance-industrial supplies sent to the improvement from the bowels of the earth; determine the rational amount of simultaneously working extractive units with the aim of providing of necessary amount and quality of commodity products; their redemption. Optimal loading set and fold the calendar graphic arts of booty of balance-industrial supplies of ferrous quartzite's on every extractive unit and determine terms.

A provision of every extractive power-shovel the industrially-balance supplies prepared to the booty is with the different degree of preparedness to the booty, and thus and on the whole depends a quarry on a time domain between loosening of array of ferrous quartzite's. Than anymore this time domain, the anymore there must be material well-being of every power-shovel removed, indignant and by other industrially-balance supplies prepared to the booty. At the same time domain between loosening of array of ferrous quartzite's in coalfaces a time domain between the mass loosening is different. Effective work of quarry in that case, when time domains between the mass loosening of array of balance-industrial supplies and loosening of array of ferrous quartzite's in coalfaces gather, id est then, when time of mass explosion coincides in all extractive coalfaces. An optimal time domain between the mass loosening of array of balance-industrial supplies in iron-ore careers is in limits from two to three weeks. Size of «transitional» removed from the array of the balance-industrial supplies of ferrous quartzite's prepared to the booty use in content of quality indexes of reserve that compensates the unevenness of the productivity of extractive units.

An aim of work is development of methodology of setting of norms of the balance-industrial supplies prepared to the booty taking into account the complex mastering of bowels of the earth.

For the achievement of the put aim such **tasks** are untied:

– it is an analysis of present methods of setting of norms of the balance-industrial supplies prepared to the booty;

– it is an improvement of existent methodologies of setting of norms of the balance-industrial supplies prepared to the booty taking into account the complex mastering of bowels of the earth;

– it is establishment of norms of the balance-industrial supplies prepared to the booty.

An idea of work is an analysis and determination of methods of calculation of the optimal balance-industrial supplies prepared to the booty for development of economy of ore-mining enterprises and indexes of plenitude of the use of resources of bowels of the earth at present lab our and material resources.

A research object is the balance-industrial supply of ferrous quartzite's prepared to the booty.

The subject of research is methodology of setting of norms of the balance-industrial supplies prepared to the booty.

Analysis of methods of setting of norms of the balance-industrial supplies prepared to the booty. From the bowels of the earth work is preceded the direct booty of balance-industrial supplies of ferrous quartzite's: on providing of norms of balance-industrial supplies of ferrous quartzite's on the degree of preparedness to the booty; to registration and claim of norms of acceptance in exploitation of extractive units, the amount of that provides the booty of different on content quality indexes of balance-industrial supplies of ferrous quartzite’s in correlations necessary for the receipt of iron-ore mass of the set content of quality indexes; determination of norms of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals at the booty of balance-industrial supplies of ferrous quartzite’s on every extractive unit and quarry on the whole; a choice of parameters of works is taking into account a minimum of losses of balance-industrial supplies at the booty of balance-industrial supplies of ferrous quartzite’s from the bowels of the earth [2,3].

Balance-industrial supplies of ferrous quartzite’s of quarry, that is ready to the booty is optimal (and they can be accepted at content of quality indexes of norm), if optimal will be indexes of $Q_г=H_г$, $N=N_0$, $d=d_0$ and etc. [4,5]. The balance-industrial supplies prepared to the booty are removed from an array must provide the planning productivity of every extractive unit in every interval between loosening of array of ferrous quartzite’s. The productivity of extractive unit on a career hesitates in wide limits in relation to her mean value that is why set the normative size of removed from the array of the balance-industrial supplies prepared to the booty with reserve. The brought totality over of means that in every interval between loosening of array of ferrous quartzite’s in the coalface of *i*-a of extractive unit to the moment of completion of shipping of the removed iron-ore mass the prepared to the booty balance-industrial supplies corresponding to the productivity of extractive unit and to the moment of completion are indignant boring works to be cleaned out and prepared to the boring drilling of blast holes, corresponding to the volume of the iron-ore mass removed for an explosion.

The chart of changeability of the removed balance-industrial supplies of ferrous quartzites in the coalface of extractive unit is brought on the figure 1*a*.

Changeability of the removed balance-industrial supplies in the coalfaces of separate extractive units and in a career it takes place on the whole salutatory with a period, that equals an interval between the contiguous loosening of array of ferrous quartzite’s and with amplitude that equals the volume of the removed iron-ore mass q_{1ij}.. The amount of the removed balance-industrial supplies of iron-ore mass of *i*-a of extractive unit on the fixed moment of time determines by such method

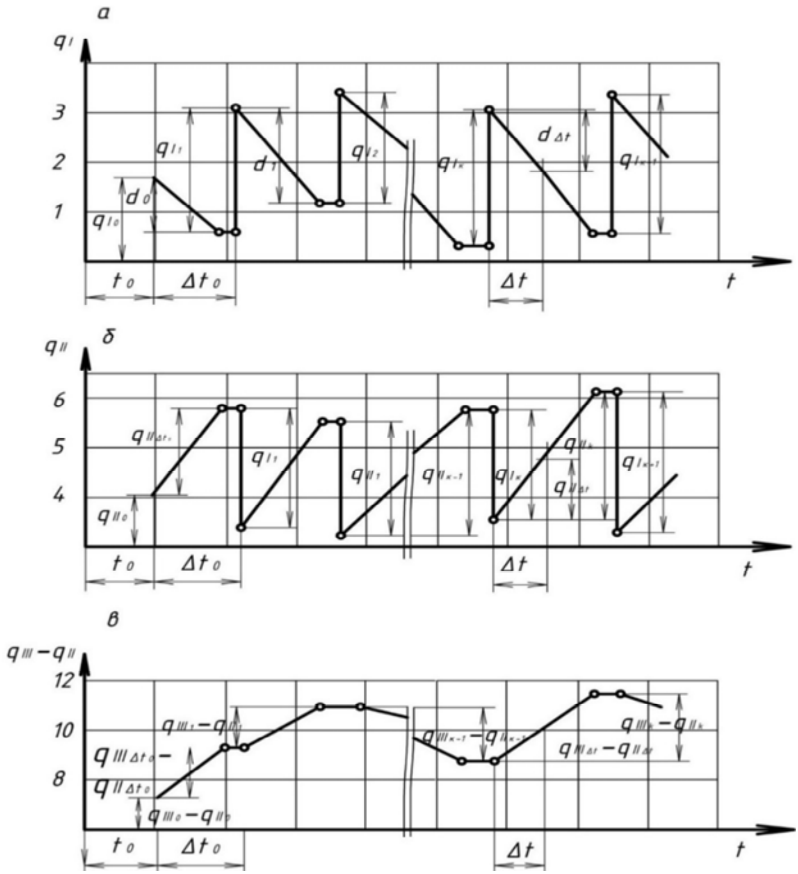

Fig. 1. Chart of changeability of balance-industrial supplies of extractive unit:
a - removed; *b* – indignant and *c* – preparation to the boring drilling blast holes

$$Q_{\mathrm{I}i} = q_{\mathrm{I}i0} + \sum_{1}^{k_i} q_{\mathrm{I}ij} - \sum_{1}^{k_i} d_{ij} - d_{i\Delta t} = q_{\mathrm{I}i0} + k_i q_{\mathrm{I}i} - (k-1)d_i - d_{i\Delta t} \quad (1)$$

where: $q_{\mathrm{I}io}$ is an amount of the removed balance-industrial supplies of array of ferrous quartzite's in the coalface of *i*-a of extractive unit in initial moment of the considered period of time of t_0; d_{i0} is an amount of iron-ore mass, that ship *i*-a extractive unit in times of Δt_0; $q_{\mathrm{I}ij}$ is an amount of balance-industrial supplies of array of ferrous quartzite's of *i*-a of extractive unit, that beat back in *j*-m and explosion; $d_{\text{I}ij}$ is the productivity of i-a of extractive unit in an interval between loosening of array of ferrous quartzite's; $d_{i\Delta t}$ is an amount of iron-ore mass that is shipped i-a by extractive unit in times of Δt; $q_{\text{I}i}$ is the AV amount of the removed balance-industrial supplies of array of ferrous quartzite's of i-a of extractive unit in an interval between loosening of array of ferrous quartzite's; d_i is the middle productivity of i-a of extractive unit in an interval between loosening of array of balance-industrial supplies.

Changeability of balance-industrial supplies of ferrous quartzite's of extractive unit of indignant by blast holes, equal as and balance-industrial supplies removed, carries salutatory character with a period that equals a time domain between the contiguous loosening of array of ferrous quartzite's. The amount of balance-industrial supplies of ferrous quartzites of i-a of extractive unit, indignant at blast holes on the fixed moment of time, determines from expression

$$Q_{\text{II}i} = q_{\text{II}i0} + q_{\text{II}i\Delta t_0} + \sum_{1}^{k_i-1} q_{\text{II}ij} - \sum_{1}^{k_i-1} q_{\text{I}ij} + \\ + q_{\text{II}i0} + q_{\text{II}i\Delta t_0} + (k_1 - 1)q_{\text{II}i} - k_i q_{\text{I}i} + q_{\text{II}i\Delta t} \quad (2)$$

where: $q_{\text{II}io}$ are balance-industrial supplies of ferrous quartzite's of i-a of extractive unit, prepared to the boring drilling blast holes, present in the moment of time of t_0; $q_{\text{II}ij}$ are balance-industrial supplies of ferrous quartzite's of i-a of extractive unit, prepared to the boring drilling blast holes in a i-a interval between loosening of array of ferrous quartzite's; $q_{\text{II}i}$. it is an average of balance-industrial supplies of ferrous quartzite's of i-a of extractive unit, prepared to the boring drilling blast holes in an interval between loosening of array of ferrous quartzite's; $q_{\text{II}i\Delta t}$ are balance-industrial supplies of ferrous quartzite's of i-a of extractive unit, prepared to the boring drilling blast holes for time Δt.

The chart of changeability of balance-industrial supplies of ferrous quartzites of extractive unit, indignant at blast holes, is brought around on chart. 1*б*. Like on the fixed moment of time the amount of balance-industrial supplies of ferrous quartzites of i-a of extractive unit of the blast holes prepared to the boring drilling will present

$$Q_{\text{III}i} = q_{\text{III}i_0} - q_{\text{II}i_0} + q_{\text{III}i\Delta f_0} + \sum_{1}^{k_i - 1} q_{\text{III}ij} - \sum_{1}^{k_i - 1} q_{\text{II}ij} + q_{\text{III}ij} - q_{\text{II}i\Delta} = \\ q_{\text{III}i_0} - q_{\text{II}i_0} + q_{\text{III}i\Delta t_0} + (k_1 - 1) q_{\text{III}i} - (k_1 - 1) q_{\text{II}i} + q_{\text{III}i\Delta t} - q_{\text{II}i\Delta t} \tag{3}$$

where: $q_{\text{III}io}$ are balance-industrial supplies of ferrous quartzite's of *i*-a of extractive unit, prepared to the boring drilling of blast holes, present in the moment of time of t_0; $q_{\text{III}ij}$ are balance-industrial supplies of ferrous quartzite's of *i*-a of extractive unit, prepared to the boring drilling of blast holes in *j*-a and interval between loosening of array of ferrous quartzite's; $q_{\text{III}i}$. it is an average of balance-industrial supplies of ferrous quartzite's of *i*-a of extractive unit, prepared to the boring drilling of blast holes in an interval between loosening of array of ferrous quartzite's; $q_{\text{III}i\Delta t}$ are balance-industrial supplies of ferrous quartzite's of *i*-a of extractive unit, prepared to the boring drilling of blast holes for time Δt.

The chart of changeability of balance-industrial supplies of ferrous quartzite's of extractive unit, blast holes prepared to the boring drilling, is brought around on chart 1*в*. Balance-industrial supplies are ready to mining of *i*-a of extractive unit in fixed moment of time present a size that equals a sum

$$Q_{\Gamma i} = Q_{\text{I}i} + Q_{\text{II}i} + Q_{\text{III}i} = (k_1 - 1) q_{\text{III}i} - (k_1 - 1) d_i + \\ + q_{\text{III}i\Delta t_0} + q_{\text{III}i_0} + q_{\text{III}i\Delta t} + q_{\text{I}i_0} - d_{i_0} - d_{i\Delta t} \tag{4}$$

If oscillation of the productivity of *i*-a of extractive unit in intervals between loosening of array of ferrous quartzite's to characterize a size middling quadratic rejection [6] then

$$q_{\text{I}i_0} = d_{i_0} + t\sigma_{di}, \tag{5}$$

where *t* is a coefficient of probability.

Normative average of the removed balance-industrial supplies of array of ferrous quartzite's prepared to the booty

$$q_{\text{I}_0} = d_0 + t\overline{\sigma}_{di}, \tag{6}$$

where $\overline{\sigma}_{di}$ – determine as AV

$$\overline{\sigma}_{di} = \frac{1}{N}\sum_{1}^{N}\sigma_{di} \ . \qquad (7)$$

Use the size of «transitional» removed from the array of the balance-industrial supplies of ferrous quartzites prepared to the booty in content of quality indexes of reserve that compensates the unevenness of the productivity of extractive units. Accept $q'_{\text{I}_0} = t\sigma_{di}$, and determine the size of coefficient of probability from actual data of work of quarry [4] in obedience to formulas

$$t_i = (d_{\max_i} - d_i)/\sigma_{di}\,, \qquad (8)$$

$$t = \frac{1}{N}\sum_{1}^{N} t_i\ , \qquad (9)$$

where $d_{\max i}$ is a burst performance of *i*-a of extractive unit.

From expression of oscillation of number of explosions in the

$$H_{\text{г}} = N_0[(k+0{,}5)q_{\text{III}_0} - (k-0{,}5)d_0 + \sigma_k(r_{kd_{\text{III}}}\sigma_{d_{\text{III}}} - r_{kd_0}\sigma_{d_0}) + q'_{\text{III}_0} + q'_{\text{I}_0}]$$

[4], considered time domain characterize that a quadratic average, influences on the norm of the balance-industrial supplies prepared to the booty. At the calculations of norms of the balance-industrial supplies of ferrous quartzite's prepared to the booty a quadratic average it is possible to ignore, because explosive works in a career must be conducted rhythmically with identical time domains between loosening of array of ferrous quartzite's. Therefore expression will accept the following

$$H_{\text{г}} = N_0[(k+0{,}5)q_{\text{III}_0} - (k-0{,}5)d_0 + q'_{\text{III}_0} + t\sigma_{d_0}]\,. \qquad (10)$$

Raising of task. At the open method of booty of ferrous quartzite's it is necessary for trouble-free and rational work of every extractive unit, that certain accordance stuck to between the different types of mountain works. Mathematically this accordance can be expressed by next correlations:

$$q_{\text{I}ij}/t_{Iij} = q_{\text{II}ij}/t_{\text{II}ij} = q_{\text{III}ij}/t_{\text{III}ij} =$$
$$= (Q_{\text{п}if} - Q_{\text{г}if})/t_{\text{п}if} = (Q_{\textit{в}i_{\phi}} - Q_{\text{II}i\phi})/t_{\textit{в}i\phi}\,, \qquad (11)$$

where $t_{\text{I}ij}$, $t_{\text{II}ij}$, $t_{\text{III}\,ij}$ accordingly time on shipping, boring drilling of blast holes and preparation to indignation of the balance-industrial supplies $q_{\mathrm{I}ij}$, $q_{\mathrm{II}ij}$, $q_{\mathrm{III}ij}$ of *i*-a of extractive unit prepared to the booty in *j*-a interval between loosening of array of ferrous quartzite's; and t_{IIij} , $t_{віф}$ is time of implementation of works on creation of the exposed ($Q_{if} - Q_{\text{г}if}$), and ready to the booty balance-industrial supplies of *i*-a of extractive unit prepared ($Q_{ві_ф} - Q_{\mathrm{II}iф}$).

The brought totality over of equalities means that in every interval between loosening of array of ferrous quartzite's in the coalface of *i*-a of extractive unit to the moment of completion of shipping of the removed iron-ore mass the prepared to the booty balance-industrial supplies corresponding to the productivity of extractive unit must be indignant; to the moment completions of boring works must be cleaned out and prepared to the boring drilling of blast holes, corresponding to the volume of the iron-ore mass removed for an explosion, and, including works on preparation and opening of balance-industrial supplies [4]. A transition from the productivity of extractive unit to the balance-industrial supplies prepared to the booty carry out taking into account the losses of the ferrous quartzite's and content of quality indexes of minerals prepared to the booty at booty. Sizes $t_{\mathrm{I}ij}$, $t_{\mathrm{II}ij}$, $t_{\mathrm{III}ij}$ in general case do not equal duration of time domain between loosening of array of ferrous quartzite's and not even inter se. Unequal are sizes $q_{\mathrm{I}ij}$, $q_{\mathrm{II}ij}$, $q_{\mathrm{III}ij}$ These indexes will be identical in idealizing case: at even time domains between loosening of array of ferrous quartzite's, to even work of all machines and equipment [4].

Exposition of material and results. Relations driven to expression (11), there are products of number of pieces of equipment on his middle productivity [4]. Yes, the first relation is the productivity on shipping of the balance-industrial supplies of ferrous quartzite's of *i*-a of extractive unit removed from an array in *j*-m interval between loosening; the second relation is a product of number of boring machine-tools of *i*-a of extractive unit on their middle productivity in *j*-m interval between loosening of array of ferrous quartzite's

$$d_{ij} = n_{\text{ст}ij} d_{\text{ст}ij} = n_{зij} d_{зij} = n_{пij} d_{пij} = n_{вij} d_{вij} \,, \qquad (12)$$

Where d_{ij} is the productivity of extractive unit, in j-m interval between loosening of array of ferrous quartzite's n_{cmij}, $n_{зij}$, n_{nij}, $n_{вij}$ it is a number of pieces of equipment accordingly on the boring drilling of blast holes, to preparation of the balance-industrial supplies prepared to the booty to indignation, on works on preparation and opening of the ferrous quartzite's of i-a of extractive unit prepared to the booty in an interval between loosening of array; d_{cmij}, $d_{зij}$, - and it is the middle productivity of piece of equipment on the boring drilling of blast holes on preparation of the balance-industrial supplies of ledge prepared to the booty to the boring drilling and in a j-m interval between loosening of array of ferrous quartzite's of j-m to obtaining

$$n_{\text{ст}} = \bar{n}_{\text{ст}} + t\sigma_{n_{\text{ст}}} . \tag{13}$$

For the calculations of indexes will use expression (12) examine that as a between's by casual sizes? Determining the expected values and dispersions of right and left parts of equality (12), will get

$$d_i = n_{\text{ст}} d_{\text{ст}} + K_{n_{\text{ст}} d_{\text{ст}}} , \tag{14}$$

$$\sigma_{di}^2 = \sigma_{n_{\text{ст}}}^2 \sigma_{d_{\text{ст}}}^2 + \bar{n}_{\text{ст}}^2 \sigma_{d_{\text{ст}}}^2 + \bar{d}_{\text{ст}}^2 \sigma_{n_{\text{ст}}}^2 + K_{n_{\text{ст}} d_{\text{ст}}}^2 + 2\bar{n}_{\text{ст}} \bar{d}_{\text{ст}} + 2\bar{n}_{\text{ст}} K_{n_{\text{ст}} d_{\text{ст}}} , \tag{15}$$

where $\bar{n}_{\text{ст}}, \cdot \bar{d}_{\text{ст}}$ are mean values, $\sigma_{n_{\text{ст}}}^2, \cdot \sigma_{d_{\text{ст}}}^2$ are dispersions, $K_{n_{\text{ст}} d_{\text{ст}}}$ is a cross-correlation moment of sizes of $n_{\text{ст}ij}$, $d_{\text{ст}ij}$.

Decide equalization (14) and (15) and get expression for the calculations of indexes. Determine the normative number of pieces of equipment an analogical method in all stages of realization of mountain works [5,6]. From correlations (11) and (12) on condition of $t_{\text{I}ij} = t_{\text{II}ij} = t_{\text{III}ij}$, where $t_{\text{I}ij}$ is a time domain between loosening of array of ferrous quartzite's, swims out, that must be executed to equality of $q_0 = q_{10} = q_{\text{II}0}$, and also $\sigma_{d0} = \sigma_{d\text{I}0} = \sigma_{d\text{II}0} = \sigma_{d\text{III}0}$, id est on the average on each there must be one ton of the iron-ore mass removed from an array, indignant, cleaned out, prepared and exposed, tone of the shipped iron-ore mass [5,6]. Therefore expression for the calculations of norm of the balance-industrial supplies prepared to the booty yet more will simplify and taking into account reserve ΔH_{r2} he will accept the following

$$H_{\text{г}} = N_0(d_0 + t\bar{\sigma}_{d_0} + q'_{\text{Ш}_0}) + П - В + \Delta H_{\Gamma_2}\,, \qquad (16)$$

where: *П*, *В* accordingly losses of the balance-industrial supplies prepared to the booty and amount of breeds of, that participate in a booty, in this period, equals a time domain between loosening of array of ferrous quartzite's in extractive coalfaces, т; ΔH_{r_2} it is reserve of the balance-industrial supplies prepared to the booty, that compensates the error of their determination, т.

A transition from the productivity of extractive unit to the balance-industrial supplies prepared to the booty carry out taking into account the losses of the ferrous quartzite's and content of quality indexes of minerals prepared to the booty at booty. This circumstance is taken into account by a formula (16). For providing of front of boring works and considerable simplification of calculations accept the size of the balance-industrial supplies prepared to the booty such that equals the size of the productivity of extractive unit.

$$H_{\text{г}} = N_0(2d_0 + t\bar{\sigma}_{d_0}) + П - В + \Delta H_{\Gamma_2}\,. \qquad (17)$$

Assuming $\Delta H_{\Gamma_2} = t\bar{\delta}_{\Gamma_2}$ [5], where *t* a coefficient of probability, δ_{r2} is a middle quadratic error of determination of normative size of the balance-industrial supplies prepared to the booty. Indexes of d_0, σd_0 and t in a formula (17) at the use of large statistical material establishment practically without errors. Therefore the error of calculations of norm of the balance-industrial supplies prepared to the booty on a formula (17) depends only on the error of determination of number of extractive units

$$\delta_{\text{г}_2} = \delta_{N_0}(2d_0 + t\bar{\sigma}_{d_0})$$

where δ_{N0} is an error of determination of number of extractive units.

Execute the calculations of number of extractive units in obedience to formulas $N'_0 = \text{к}_1 Д_{\text{п}} / n_{\text{к}} \overline{\text{к}d}_{\text{зм}}$; $\Delta = t\sigma$ [5,6]. Indexes that are included in these formulas set a plan, or determine on the basis of the statistical processing of actual data practically without errors. Therefore by the error of determination of number of extractive units, and thus, and at the calculations of norm of the balance-industrial supplies prepared to the booty it is possible the error of determination of reserve of the balance-industrial supplies prepared to the booty to scorn.

In obedience to a formula (17) the average of the transitional removed balance-industrial supplies prepared to the booty equals on a career $N_0 t\overline{\sigma}_{d_0}$. The conducted analysis showed that this size in the conditions of iron-ore quarries of Kryvyi Rih can be accepted by such that equals 0,3 the average monthly productivity of ore-mining enterprise. Such size is sufficient for indemnification of vibrations of the productivity of extractive power-shovels at the motor-car transporting of iron-ore mass from extractive coalfaces. However at the railway transporting of iron-ore mass such reserve of the transitional removed balance-industrial supplies prepared to the booty can appear insufficient. It is therefore expedient in a formula (17) to enter a coefficient that takes into account the increase of the balance-industrial supplies prepared to the booty at the railway transporting. Then a norm of the balance-industrial supplies prepared to the booty will bq

$$H_{\text{г}} = N_{0_1} d_{0_1} (2 + tV_{d_1}) + N_{0_2} d_{0_2} (2 + k'_{\text{т}} tV_{d_1}) + \Pi - B, \quad (18)$$

where N_{01}, N_{02} is a number of extractive power-shovels that work accordingly on a motor and railway transport, with the observance of condition of $N_0=N_{01}+N_{02}$.

In general case for the m types of transport

$$H_{\text{г}} = \sum_1^m N_{0_j} d_{0_j} (2 + k'_m tV_{d_j}) + \Pi - B. \quad (19)$$

The expounded methodology of setting of norms of the balance-industrial supplies prepared to the booty, based on the use of dependence (17), is widely approved on the careers of Kryvyi Rih. The methodology of setting of norms of preparedness of the balance-industrial supplies prepared to the booty, worked out for operating ore-mining enterprises, is not quite comfortable however, because the row of indexes determines from data of work of operating ore-mining enterprise. In connection with it methodology of setting of norms of preparedness of the balance-industrial supplies prepared to the booty is modernized and adjusted to the use on the stage of planning. Indexes and coefficients, that is included in a formula (17), characterize correlation of separate constituents of the balance-industrial supplies(indignant and prepared to the boring drilling blast holes removed) prepared to the booty, type of transporting of iron-ore mass and unevenness of extractive works. Coefficient «2» in this formula is set subject to condition, in accordance with that, to the moment of loosening of array in ferrous quartzites in extractive coalfaces. Such assumption it is possible and not to do, but the size of the «transitional» balance-industrial supplies blast holes prepared to the boring drilling prepared to the booty, to estimate by means of coefficient of material well-being that takes into account presence in composition the balance-industrial supplies prepared to the booty cleaned out blast holes prepared to the boring drilling. In this case expression for the calculations of norm of the balance-industrial supplies prepared to the booty will assume a next view

$$H_{\text{г}} = N_0 d(1 + tV_d)k_{\text{т}}k_{\text{з}} + П - В\,, \tag{20}$$

where $k_{\text{т}}$ is a coefficient that takes into account the increase of the balance-industrial supplies prepared to the booty at the railway transporting of mountain mass from coalfaces in comparing to motor-car.

The coefficient of material well-being shows, at the balance-industrial supplies how many times prepared to the booty more sum of removed and indignant. The values of indexes, that is included in a formula (20), depend on the applied technique and technology of open method of booty of balance-industrial supplies from a deposit, bed, ore body or areas. Will lead

$$k_{\text{р}} = N_0'' / N_0' \ldots\ldots \tau_{\text{м}} = \tau_{зм} / n_{\text{к}} \ldots\ldots d = \tau_{\text{зм}} k_{\text{и}} d_{\text{зм}}\,,$$

where k_p is a coefficient of reserve of extractive units; $\tau_{\text{м}}$, $\tau_{\text{зм}}$ is a time domain between loosening of array of ferrous quartzite's in an extractive coalface accordingly in months and in changes.

Using these dependences will get a formula for the calculations of norm of the balance-industrial supplies prepared to the booty in time (in months) units:

$$H_{\text{г}}' = 1{,}05(1 + tV_d)k_{\text{з}}k_{\text{т}}k_{\text{р}}\tau_{\text{м}} + \frac{П - В}{Д_{\text{м}}}\,. \tag{21}$$

For determination of mean values of indexes of *t* and V_d data of daily variably-allowance charts of work of iron-ore quarries of Kryvyi Rih are used, and in a formula (21) at the calculations of norms of the balance-industrial supplies prepared to the booty it is possible the last addition to scorn (table. 1).

Table 1

For determination of mean values of indexes of *t* and V_d data of daily variably-allowance charts of work of iron-ore quarries of Kryvyi Rih are used

Ore-mining enterprises	Value of indexes of V_d (in a numerator) and *t* (in a denominator) depending on a time (in weeks) domain between loosening of array of ferrous quartzite's in extractive coalfaces			
	1	2	3	4
Inguletz CRG	0,57/2,11	0,48/1,41	0,44/1,54	0,41/1,47
South CRG	0,51/1,98	0,35/1,79	0,35/1,65	0,34/1,42
Novo-Krivorizkiy CRG «ArselorMittal»	0,52/1,77	0,37/1,76	0,33/1,63	0,36/1,46
Central CRG	0,53/1,62	0,44/1,68	0,38/1,45	0,42/1,56
North CRG	0,53/1,76	0,48/1,87	0,32/1,68	0,28/1,41
AV	0,53/1,85	0,42/1,71	0,37/1,59	0,36/1,46

During work on a railway transport in a loosening block that provides the a week's productivity of power-shovel, when approximately 30 from the array of balance-industrial supplies is in the distance from the axis of railway way that exceeds a 25 m, mountain mass is shipped with overcastting with mountain mass of next block that increases the removed balance-industrial supplies ready to mining in 1,3 times (figure. 2).

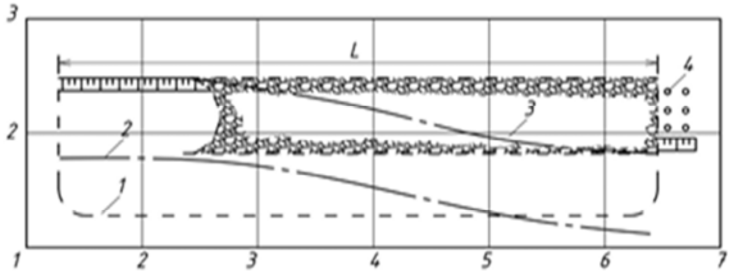

Fig. 2.. Chart to the calculations of the transitional removed balance-industrial supplies during work on a railway transport: L is length of loosening array of block; 1 is a contour of loosening array of block; 2 is an axis of railway way; 3 is a contour of the transitional removed balance-industrial supplies; 4 are blast holes

At the calculations of norm of balance-industrial supplies of the minerals prepared to the booty in this case it follows to accept $k_{т}$=1,3. With the increase of volume of block, that loosen the value of coefficient of $k_{т}$ will diminish. For blocks that provide two-week work of power-shovel, at the calculations of norm of balance-industrial supplies of the minerals prepared to the booty it follows to accept $k_{т}$=1,15, of four weeks – $k_{т}$=1,08. For the estimation of size of coefficient of $k_{з}$ the executed analysis of correlations of the balance-industrial supplies prepared to the booty removed, indignant and prepared to the boring drilling blast holes. An analysis is conducted in the conditions of iron-ore quarries of Kryvyi Rih. By a feedstock for an analysis became given to the account of the indignant and cleaned out prepared to the booty balance-industrial supplies removed, on extractive ledges that present in a sum the balance-industrial supplies prepared to the booty. The got results on the careers of Kryvyi Rih CRG drawn on for the estimation of middle between's between the indignant and cleaned out industrial prepared to the booty supplies of ferrous quartzite removed, driven to the table. 2.

Table 2

An estimation of middle between's by the indignant and cleaned out prepared to the booty balance-industrial supplies removed

Ore-mining enterprises	Balance-industrial supplies of ferrous quartzite's prepared to the booty		
	removed	indignant	cleaned out
Inguletz CRG	39,8	37,1	23,1
South CRG	52,8	28,5	18,7
Novo-Krivorizkiy CRG «ArselorMittal»	41,6	29,6	28,8
Central CRG	41,4	32,7	25,9
North CRG	51,2	29,6	19,2
Mean value	45,4	31,5	23,1

Thus, by an experience way from data of work of iron-ore quarries of Krivbass the set values to the coefficient of reserve of extractive units, time domain between loosening of array of ferrous quartzite's in an extractive coalface accordingly in months and in changes.

Using the set values of indexes and coefficients, at presence of in the career of the motor-car and railway transporting of iron-ore mass from coalfaces for different time domains dependences are got for the calculations of norms of the balance-industrial supplies prepared to the booty that is driven to the table. 3.

Table 3

Dependences are for the calculations of norms of the balance-industrial supplies of ferrous quartzite's prepared to the booty

A type of transporting of iron-ore mass is from coalfaces	Expression is for the calculation of norms of the balance-industrial supplies of ferrous quartzite's prepared to the booty in different time τ_m, miss domains			
	0,23	0,47	0,69	0,93
Motor-car	$H'_г=0{,}61k_p$	$H'_г=1{,}18k_р$	$H'_г=1{,}58k_p$	$H'_г=1{,}91k_p$
Railway	$H'_г=0{,}83k_p$	$H'_г=1{,}33k_р$	$H'_г=1{,}67k_p$	$H'_г=1{,}98k_p$
Combined	$H'_г=(0{,}61p_1+$ $+0{,}83p_2)k_p$	$H'_г=(1{,}18p_1+$ $+1{,}33p_2)k_p$	$H'_г=(1{,}58p_1+$ $+1{,}67p_2)k_p$	$H'_г=(1{,}91p_1+$ $+1{,}98p_2)k_p$

In the table of size of p_1 and p_2 mark accordingly the motor-car and railway transporting of iron-ore mass from coalfaces in a career. At the calculations of norms of balance-industrial supplies of the minerals prepared to the booty on the stage of planning most difficulties are caused by determination of middle for inwardly slaughter dispersion of content of quality indexes of useful component mean that.

Taking into account numerous requirements to inside quarry average of content of quality indexes of minerals in iron-ore mass at setting of norms of preparedness of balance-industrial supplies, from one side, difficult, and from other - beside the purpose, because these requirements not always are reasonable, often duplicate each other and not controlled fully. It is Therefore expedient to conduct the analysis of requirements on inside-mining blending of quality indexes of minerals in iron-ore mass with an aim them substantial simplification and clarification. If blending of content of quality indexes of minerals in iron-ore mass in a career carry out for to a few useful components, then it follows to reduce the presence of dependences between them. The presence of reliable dependences between content of useful components that averages in iron-ore mass that comes from a quarry on an ore mining and processing factory allows asserting about the presence of dependences between descriptions of changeability of content of these useful components. In that case, when between standard deviations of content of useful components that average, there is substantial correlation, then blending of content of quality indexes of minerals in iron-ore mass can be conducted on one of useful components, determination of that is simpler and cheap. In general to limit oscillation of two interdependent useful components beside the purpose. It is enough to limit oscillation of content of one useful component. It position is known and confirmed experimentally [7-9].

Before blending of content of quality indexes of minerals in iron-ore mass obtain that different requirements operate on careers:

- it is limitation of oscillation of content of useful and harmful components in the different volumes of the obtained iron-ore mass (mostly in variables and day);

- on iron-ore careers content of quality indexes of minerals in iron-ore mass, that supply with on an ore mining and processing factory, limit oscillation of content of quality indexes of iron general, or content of quality indexes of the iron related to magnetite, sculptures and silica in variables and daily allowance volumes of balance-industrial supplies of minerals.

For simplification of calculations there was the tested hypothesis about the presence of connection between middle for quadratic and middle for quadratic inters laughter dispersions of content of quality indexes of the iron related to magnetite. Size middle for quadratic and middle for quadratic inters laughter dispersions of content of quality indexes of iron related to magnetite, from different parties characterize changeability of quality indexes of minerals in the bowels of the earth and in iron-ore mass obtain that. In the same time they are descriptions of the same part of array of ferrous quartzites, general totality that allows assuming the presence of correlation between these indexes. For an analysis data that is set on the ore-mining enterprises of Krivbass are used [4].

	$\overline{\sigma}^2$	$\overline{\delta}^2$
Inguletz CRG	20,6	7,8
South CRG	10,6	6,2
Novo- Krivorizkiy CRG «ArselorMittal»	10,2	3,6
Central CRG	24,4	12,2
North CRG	12,3	7,5

The conducted cross-correlation analysis shows that between the considered sizes there is dependence as a line, that to pass from beginning of coordinates

$$\overline{\sigma}^2 = 2{,}2\delta^2 . \tag{22}$$

$$N_0'' = \frac{\delta^2 (2{,}2 + 3{,}2V_d^2)}{\sigma_0^2 k_y^2} - V_d^2 . \tag{23}$$

Numerous determinations of coefficient of variation of variable-stroke of extractive power-shovels showed that V_d=0,4÷0,5, not taking into account the last addition in a formula (19), will get

$$N_0'' = \frac{3\delta^2}{\sigma_0^2 k_y^2} . \tag{24}$$

From expression (24) comes out, that

$$k_{\text{p}} = 3\delta^2 / \sigma_0^2 k_{\text{y}}^2 N_0 . \tag{25}$$

Generalization of data of work of iron-ore quarries of Krivbass testifies that the size of coefficient of blending of content of quality indexes of minerals in iron-ore mass changes in limits from 1 to 1,5, and his value depends on the capacity of composition of blending of content of quality indexes of minerals in iron-ore mass and warehousing technology stated below.

Compositions of blending of content of quality indexes of minerals in iron-ore mass and compositions of blending of content of quality indexes of minerals in iron-ore mass on shifting grounds are absent 1

Compositions of blending of content of quality indexes of minerals in iron-ore mass by a capacity to 50 thousand т.. 1,1

Compositions of blending of content of quality indexes of minerals in iron-ore mass by a capacity 100-200 thousand т, including shifting compositions of blending of content of quality indexes of minerals in iron-ore mass 1,2-1,3

Compositions of blending of content of quality indexes of minerals are in iron-ore mass by a capacity over 300 thousand т with the layer conclusion of iron-ore mass and shipping of the reaching...1,4-1,5

Thus, determine the coefficient of reserve of number of extractive units depending on changeability of content of quality indexes of minerals in an array, requirements to inside quarry blending of content of quality indexes of minerals in iron-ore mass and efficiency of the system of blending of content of quality indexes of minerals in iron-ore mass on a ore-mining enterprise. Indexes that are included in expression (25) will set on the stage of planning of ore-mining enterprise. Dependences that is driven to the table. 3, allow to expect the norms of the balance-industrial supplies prepared to the booty depending on the coefficient of reserve, time domain between loosening of array of ferrous quartzite's and type of transporting of iron-ore mass from coalfaces. The calculations of norms are executed for the iron-ore quarries of Krivbass. Results are driven to the table. 4.

Table 4

Dependences for the calculation of norms of the balance-industrial supplies of ferrous quartzite's prepared to the booty depending on the coefficient of reserve of time domain between loosening of array of ferrous quartzite's and type of transporting of iron-ore mass from coalfaces for the terms of quarries of Krivbass

Interval between loosening of array of ferrous quartzite's, τ months	Coefficient of reserve, k_p	Norms of the balance-industrial supplies of ferrous quartzite prepared to the booty are depending on part of the motor-car (p_1) and railway (p_2) transporting from extractive coalfaces					
		p_1=1 p_2=0	p_1=0,8 p_2=0,2	p_1=0,6 p_2=0,4	p_1=0,4 p_2=0,6	p_1=0,2 p_2=0,8	p_1=0 p_2=1
0,23	1,0	0,7	0,7	0,7	0,7	0,7	0,8
	1,5	0,9	1,0	1,1	1,1	1,1	1,2
0,47	1,0	1,2	1,2	1,2	1,3	1,3	1,4
	1,5	1,8	1,8	1,9	1,9	2,0	2,0
0,69	1,0	1,6	1,6	1,6	1,6	1,7	1,7
	1,5	2,4	2,4	2,4	2,5	2,5	2,6
0,93	1,0	1,9	1,9	2,0	2,0	2,0	2,0
	1,5	2,9	2,9	2,9	3,0	3,0	3,0

Thus maximally use the balance-industrial supplies prepared to the booty, diminish the number of mass explosions and outages of quarry during explosive works. Results of researches showed that an optimal time domain between the mass loosening of array of balance-industrial supplies in iron-ore careers was in limits from two to three weeks. On a formula (21) and table determine 4 norms of the balance-industrial supplies prepared to the booty depending on the size of time domain between loosening of array of ferrous quartzite's, but on the stage of planning of the use of such index for the calculations of norms of the balance-industrial supplies prepared to the booty presents certain difficulties.

As a rule, at planning technology of exploding works is not gone into detail and a time domain between loosening of array of balance-industrial supplies of ferrous quartzite's in extractive coalfaces is not determined. Therefore expediently to replace this index other, more user-friendly at planning. With a time domain between loosening of array of ferrous quartzite's in coalfaces constrained time domain between the mass loosening of array of balance-industrial supplies and productivity of quarry on rocky mass. This dependence is conditioned by limitation numbers of blocks that loosen simultaneously, during a mass explosion. If maximal number of blocks that loosen during the mass explosion of N_{max}, number of extractive units of N, that provide the production capacity of quarry $Д_{гмо}$ of on rocky mass, less than or equals the maximal number of blocks, then between loosening does not depend a time domain on the production capacity of quarry, thus at $N=Nmax$, $Д_{гм}=Д_{гмо}$ and $\tau_м=\tau_{мо}$. In area of $N>N_{max}$ takes place increase of the productivity for on iron-ore mass of $Д_{гм}>Д_{гмо}$ and increase of time domain between loosening of array of balance-industrial supplies of ferrous quartzite's $\tau_м>\tau_{мо}$ figure 3.

For the calculation of norms of the balance-industrial supplies prepared to the booty it is necessary to set dependence of size of time domain between loosening of array of ferrous quartzite's in rocky coalfaces from the production capacity of quarry on rocky mountain mass. Thus it follows to take into account a between's by the volumes of booty of balance-industrial supplies of ferrous quartzite's and rocky mass. If correlation such remains permanent, then changeability of size of time domain between loosening of array of ferrous quartzite's in rocky coalfaces will be analogical to changeability of size of time domain between loosening of array of ferrous quartzite's, that represented on figure 3.

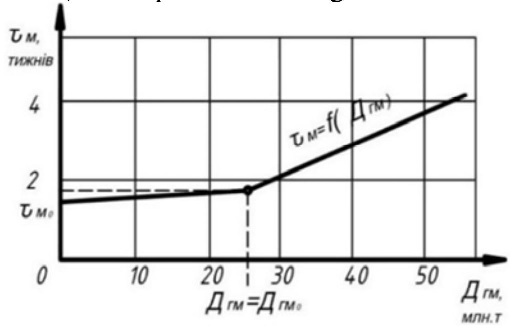

Fig. 3. Dependence of time domains between loosening of array of ferrous quartzite's in extractive coalfaces from the productivity of quarry on rocky mountain mass

However in general case (for the same time domain) of relation of time domain between loosening of array of ferrous quartzite's in rocky coalfaces will be anything. Thus dependence $\tau_{\text{мг}}=f_{\tau}(Д_{\text{гм}},\mu)$ is system of lines, each of that answers the defined value of index of time domain between loosening of array of ferrous quartzite's in rocky coalfaces. Schematically this dependence is shown on figure. 4.

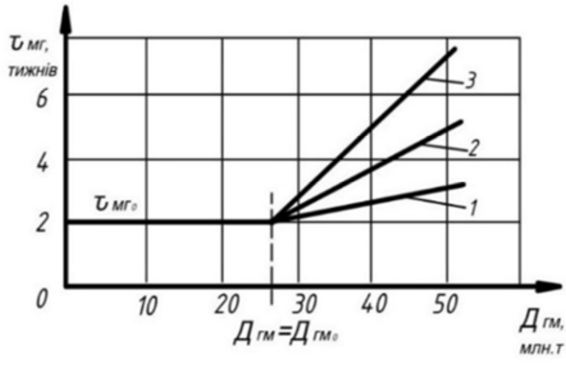

Fig. 4. Dependence of time $\tau_{мг}$ domain between loosening of array of ferrous quartzite's in rocky coalfaces from the productivity of quarry on rocky mountain mass at different between's by the volumes of booty of useful fossil and rocky mountain mass: 1 - μ=1; 2 - μ=1,2; 3 - μ=1,4

Variant μ=1,0 answers absence in the career of the rocky opening and on chart. 4 this variant is shown by the line located in the underbody of bunch of lines. The angular coefficient of lines in a bunch grows with the increase of index of time domain between loosening of array of ferrous quartzite's in rocky.

At an unchanging technique and technology of mountain works and permanent time domain between the mass loosening of array of ferrous quartzite's dependence $\tau_м=f(Д_{гм})$ in area of $N>N_{max}$ has the appearance of line. As the conducted analysis of work of iron-ore quarries of CRG Kryvyi Rih number of ore blocks that simultaneously mass loosen does not exceed six, showed. It is related to the technique and technology of drilling-and-blasting works, geological and mine technical terms, requirements of rules of accident prevention. If to assume, that all rocky mass on a career is presented by minerals then under right technological planning of ore-mining enterprise of ferrous metallurgy for six extractive power-shovels a quarry must answer with the productive productivity 30 million т. on a year [10]. For quarries with the higher productivity in connection with the increase of number of extractive power-shovels time domain between loosening of array of ferrous quartzite's in coalfaces (at the same time domain between the mass loosening of array. For such terms of between's by time domains and productive productivity of quarry driven to the table. 5.

Table 5

There is a between's by time domains and productive productivity of quarry

Production capacity of quarry on rocky mass of $Д_{ГМ}$, млн. т	Time domain between loosening of array of balance-industrial supplies of ferrous quartzite's, week(month)							
	Mass loosening	Loosening is in extractive coalfaces	Mass loosening	Loosening is in extractive coalfaces	Mass loosening	Loosening is in extractive coalfaces	Mass loosening	Loosening is in extractive coalfaces
20	1(0,23)	1,0(0,23)	2(0,47)	2(0,47)	3(0,69)	3,0(0,71)	4(0,93)	4(0,93)
25	1(0,23)	1,5(0,35)	2(0,47)	3(0,69)	3(0,69)	4,5(1,05)	4(0,93)	6(1,41)
30	1(0,23)	2,0(0,47)	2(0,47)	4(0,93)	3(0,69)	6,0(1,41)	4(0,93)	8(1,86)
35	1(0,23)	2,5(0,58))	2(0,47)	5(1,16)	3(0,69)	7,5(1,75)	4(0,93)	10(2,33)

Dependences are between the sizes of time domain between loosening to the array and have the appearance of lines $\tau_{м1}=t_{he}$ productive productivity of quarry $\tau_{м1}$=0,0077$Д_{гм}$; $\tau_{м2}$=0,0157$Д_{гм}$; $\tau_{м3}$=0,0233$Д_{гм}$; $\tau_{м4}$=0,0310$Д_{гм}$, that can be used for time domains between the mass loosening of array of ferrous quartzite's that equal weeks accordingly. If the brought dependences over to put in a formula (21), then determine the normative size of the balance-industrial supplies prepared to the booty as a function of the productivity of quarry on mountain mass (in default of breeds of the rocky opening). Dependences for the calculations of norms of the balance-industrial supplies prepared to the booty are driven to the table 6.

Table 6

Dependences are for the calculations of norms of the balance-industrial supplies of ferrous quartzite's prepared to the booty

A time τ_m domain is between the mass loosening of array of ferrous quartzite's in a career, week	Dependences are for the calculations of norms of the balance-industrial supplies prepared to the booty at the use of transport		
	motor-car	Railway	combined
1	$H'_г$=0,0210 $k_p Д$	$H'_г$=0,0273 $k_p Д$	$H'_г$=(0,0210p_1+0,0273p_2) $k_p Д$
2	$H'_г$=0,0389 $k_p Д$	$H'_г$=0,0447 $k_p Д$	$H'_г$=(0,0389p_1+0,0447p_2) $k_p Д$
3	$H'_г$=0,0521 $k_p Д$	$H'_г$=0,0563 $k_p Д$	$H'_г$=(0,0521p_1+0,0563p_2) $k_p Д$
4	$H'_г$=0,0639 $k_p Д$	$H'_г$=0,0665 $k_p Д$	$H'_г$=(0,0639p_1+0,0665p_2) $k_p Д$

As an example the norms of balance-industrial supplies of the ferrous quartzite's prepared to the booty are expected for a time domain between the mass loosening of array $\tau_м$=0,47 months (table. 7).

Table 7

Norms of the balance-industrial supplies of ferrous quartzites prepared to the booty are for a time domain between the mass loosening of array

Д, mln.t	k_p	Norms of the balance-industrial supplies of ferrous quartzite's prepared to the booty at motor-car p_1 and railway p_2 transporting of mountain mass from extractive coalfaces					
		p_1=1,0 p_2=0,0	p_1=0,8 p_2=0,2	p_1=0,6 p_2=0,4	p_1=0,4 p_2=0,6	p_1=0,2 p_2=0,8	p_1=0,0 p_2=1,0
20	1,1	1,3	1,3	1,4	1,4	1,4	1,5
25	1,2	1,5	1,5	1,5	1,6	1,6	1,7
30	1,3	1,6	1,6	1,6	1,7	1,7	1,8
35	1,4	2,1	2,1	2,1	2,2	2,3	2,3
40	1,5	2,4	2,4	2,5	2,5	2,6	2,7

In connection with the tendency of increase of the productivity of obtaining units on the booty of balance-industrial supplies and opening breeds the size of the productive productivity of quarry on rocky mountain mass in a prospect must increase. In addition, in connection with the improvement of technique and technology of explosive works increase the number of blocks, that simultaneously use during a mass explosion that conduces to the increase the sizes of the productive productivity of quarry on rocky mountain mass, and thus, to the increase of range of changeability of the productive productivity of quarry in that the size of time domain does not depend on the productive productivity.

Thus, by an experience way from data of work of iron-ore quarries of Kryvyi Rih the set values to the coefficient of reserve of extractive units, time domain between loosening of array of ferrous quartzite's in an extractive coalface accordingly in months and in changes. Using the set values of indexes and coefficients, at presence of in the career of the motor-car and railway transporting of iron-ore mass from coalfaces for different time domains dependences are got for the calculations of norms ready to the booty of balance-industrial.

Conclusions

1. The brought totality over of means that in every interval between loosening of array of ferrous quartzite's in the coalface of *i*-a of extractive unit to the moment of completion of shipping of the removed iron-ore mass the prepared to the booty balance-industrial supplies corresponding to the productivity of extractive unit must be indignant; to the moment completions of boring works must be cleaned out and prepared to the boring drilling of blast holes, corresponding to the volume of the iron-ore mass removed for an explosion.

2. A transition from the productivity of extractive unit to the balance-industrial supplies prepared to the booty carry out taking into account the losses of the ferrous quartzite's and reduction content of quality indexes of minerals prepared to the booty at a booty. On the basis of analysis of middle correlations of the balance-industrial supplies prepared to the booty removed, indignant and prepared to the boring drilling blast holes the executed estimation of coefficient of material well-being.

3. The average of the transitional removed balance-industrial supplies prepared to the booty in the conditions of iron-ore quarries of Kryvyi Rih equals 0,3 the average monthly productivity of ore-mining enterprise and is sufficient for indemnification of vibrations of the productivity of extractive power-shovels at the motor-car transporting of iron-ore mass from extractive coalfaces.

4. Methodology of setting of norms of preparedness of the balance-industrial supplies prepared to the booty is modernized and adjusted to the use on the stage of planning. Indexes and coefficients characterize correlation of separate constituents of the balance-industrial supplies (indignant and prepared to the boring drilling blast holes removed) prepared to the booty, type of transporting of iron-ore mass and unevenness of extractive works.

5. By an experience way from data of work of iron-ore quarries of Kryvyi Rih the set values to the coefficient of reserve of extractive units, time domain between loosening of array of ferrous quartzite's in

an extractive coalface accordingly in months and in changes, at presence of in the career of the motor-car and railway transporting of iron-ore mass from coalfaces for different time domains dependences are got for the calculations of norms of the balance-industrial supplies prepared to the booty.

6. At the calculations of norms of balance-industrial supplies of the minerals prepared to the booty on the stage of planning most difficulties are caused by determination of middle for inwardly-slaughter dispersion of content of quality indexes of useful component blend that.

7. Determine the coefficient of reserve of number of extractive units depending on changeability of content of quality indexes of minerals in an array, requirements to of content of quality indexes of minerals in iron-ore mass and efficiency of the system of content of quality indexes of minerals in iron-ore mass on ore - mining enterprise.

8. A time domain between loosening of array of ferrous quartzite's in extractive coalfaces is one of basic indexes, use that for determination of normative size of the balance-industrial supplies prepared to the booty, that conducted by an explosive method.

9. Dependences between the sizes of time domain between loosening of array and productive productivity of quarry have the appearance of lines, use that for time domains between the mass loosening of array of ferrous quartzite's that equal according to one, two, three and to four weeks and determine the norm of the balance-industrial supplies prepared to the booty as a function of the productivity of quarry on mountain mass.

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DEVELOPMENT OF UNDERGROUND TECHNOLOGY FOR THE PRODUCTION OF COAL-BASED PLASTS WITH COMPLEX CONDITIONS OF ZANGING

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Problem formulation. One of the priorities adopted by the Government of the Republic of Kazakhstan the concept of development of mining industry in Kazakhstan for the period up to 2020 is a robotics and automation of production processes, environmental safety, and measures to reduce the negative impact on the environment of people. The development of coal seams underground way a negative impact on the state of land resources and causes as environmental and socio-economic damage. Implementation bezot-waste technologies requiring excavation of coal seams, is the creation of scientific bases of Mining robotics, as well as the preparation of engineering and design development elements, devices, systems of control of mining robots.

Highlight unsolved problems. Currently, in most cases, the management of mining and excavation units, complexes of exercises people - the operator who is required to continuously monitor the process and operational management process. This situation is determined by the ability of units, systems automatically edit or change a program of action to take decisions in the cases of technological change in the situation (the change of the hardness of rocks, the appearance of areas of waste rock) to make independent decisions.

In existing systems should be organized and ongoing support of the communication channel unit with a man - operator.

In carrying out technological operations operator, receiving from the system object information management and process continuously monitors and controls the actuators of the whole complex. The complexity of the process, adverse conditions in conjunction with the nature of work, requiring attention, leading to operator fatigue and, consequently, increase the likelihood of erroneous actions.

However, despite the significant development and wide application of the considered automated-bathroom units, complexes, it should be noted that the existing system does not have the ability to produce the election recess necessary under development seams with complex hypsometry, with the presence of rock layers and solids, as well as geological faults that is characteristic of deposits of the Karaganda coal basin.

Analysis of recent researches. In Eurasian National University. Gumilev (Astana) is currently on "Research and development of technology for cleaner mining complex robotic selective on the basis of standard equipment (CMRAPCS)" scientific research work is performed. ENU. L.N Gumilev and Karaganda State Technical University (KSTU) (Kazakhstan, Karaganda), together with coal department (CD) JSC "ArcelorMittal Temirtau" and LLP "Karaganda Engineering Consortium" lead the development of industrial-innovation project "Treatment robotic complex adaptive control (CMRAPCS)

The greatest development work on mine robotics and software control technological processes-sky gained in the UK, Japan, USA, Germany, and Czech Republic. For example, since 1995 the United States began extensive use of robotic manipulators for drilling (company "Fanuk"), the installation of the concrete lining in tunnels tubing (firm "Dainik").Robotic automation of mining operations in the UK carried out under the state program.

The control system is mounted on the main shaft "Ellalont" (Australia) provides for remote control the following operations: unloading, shifting, the thrust support units, advancing the conveyor extension and retraction of the flexible lining console. This system is based on a low-current electronic equipment in intrinsically safe design. The operator can unload and move the bursting roof support and move the conveyor.

Such control is carried out remotely within the support units 25 on either side of the currently controlled section.

The mine "Raspadskaya" production association "Juzhkuzbassugol" tested hardware remote and automated control mounted in the part of the experimental sample set KM138, machinery wireless remote control combine with an infrared channel-type USM and control equipment for hypsometry reservoir sensor "rock - coal" type "Quantum -III ».

The mechanic (automatic) complexes KM-137A, KAM and KMS (for layers of 0.8 to 1.5 m), KM138A (from 1.2 to 2.5 m), the frontal aggregate AFC units (for layers from 0.65 to 0.9 m) and F-1 used machinery automation of several independent or related information systems to implement automatic, remote and automated for operator commands Modes crepe. It was possible to change the order of the operator of advancing sections (serial, chess), size groups. On the center console displays information about the state of the harvester, conveyor and magnetic station.

Automated frontal combines AFC such as RKU, KA, KAS were equipped with tracking subsystems abroad "coal-rock" have a wireless radio or infrared control. The unit is controlled by the AFC from the control panel in the haulage drift.

Institute "Donavtomatgormash" together with the agricultural association "EMAG" (Poland) created by means of automation production equipment: hydraulic and electrohydraulic actuators for the automation of downhole equipment; specialized microcomputer for installation on water treatment and road headers; Laser dial destinations for mining and face equipment management system using infrared radiation.

The issues of mining robotics technology deserted recesses of very thin layers of steep engaged in research institutes and universities of Russia (Institute of Coal SD AS Russia, MI them. AA Skochinskiy, MMI, Novocherkassk Polytechnic Institute), Ukraine (Institute of Geotechnical Mechanics of NAS of Ukraine, Institute of geological Sciences of Ukraine).

Selection of the unsolved part of the overall problems. Remove of attempts the existing shortcomings in the project made to create robotic systems for coal mining without constant presence of people in the working face CMRAPCS, which uses a microprocessor control system with automatic remote controlled excavation arm of the EFM, powered roof supports and longwall conveyor providing:

-automatic control of the excavation arm for a given program;
- management of powered roof supports for a given program;
- management of reversible conveyor to drift;
- management of the face conveyor;
- management of stowing complex "Titan";
- automatic control of the load at different diameters incisal crowns EFM;
- changes in the work program of the complex, depending on geological conditions;
- remote control of the excavation arm and powered roof supports;
- providing the necessary protections and interlocks.

The control system includes a local management system and the EFM bolting devices transmit and receive information, control device.

Microprocessor control robotic systems for selective extraction performed by the KR580IK80A module interface circuits implemented on the 132 series chips, programmable read-only memory BIS KT556RT5.

The system pipe can be connected to the interface for the automatic control of the complex. A set of such devices and corresponding to different processing circuits slaughter program management module is placed in a programmable memory, used to handling complex in the various modes of coal mining, taking into account hypsometry formation.

Formulation of performance goals. Goal is the development and creation of prototype of robot technology complex on the basis of purification complex "Glinnik" (Poland), where in the excavation tools used mining excavation arm front steps of the EFM-4NA (fig. 1 and table. 1) and the implementation of pilot research health complex

1. The state of the issue of the development of coal seams, lying in the difficult conditions of the Karaganda basin

The Karaganda coal basin is located in the central part of Kazakhstan and is a syncline. Its area is about 4000 km^2, of which 2000 km^2 is accounted for by productive deposits. The periods of the highest flowering of the basin are the 1970-90s.

The coal-bearing thickness of the basin contains up to 80 coal seams with a total thickness of up to 110 m. Until the 1990s, in the Karaganda basin, coal mining was carried out by 26 coal mines out of 27 suitable for the gross excavation of mines. As a result of liquidation, merger, restructuring and other activities from 26 mines of the basin with an annual capacity of about 50 million tons per year, there are 12. Currently, coal is mined by 8 mines of the Coal Department of JSC "ArcelorMittal Temirtau" and 4 mines of the APP "Gefest". Now the mines UD annually produce up to 10-12 million tons of coal.

Losses of coal in the Karaganda basin with the formation and construction of mines in more than 80 years, amounted to over a billion tons, which is almost 40-50%.

The Karaganda coal basin is divided into the following most important coal-bearing areas: Karaganda, Churubay-Nurin and Tentek. The coal-bearing stratum of the basin is divided into six coal formations. Industrially productive are the Ashlyarik, Karaganda, Dolinskaya, and Tentekskaya suites, which are related to carboniferous sediments.

The Karaganda Formation was for a long time the main working suite of the basin. Its thickness reaches 600-800 m. The composition of the formation includes about 40 seams of coal and interlayers.

Currently, the layers of the Saragensky Karagandin Formation and the beds of the valley of the Tentha Precinct are predominantly processed. In the Dolinskaya suite there are 11 beds. Coals are low-ash, easily-enriched. The angle of incidence of the beds varies from 10 to 25°.

The technology of reservoir development, which was used for many years in coal mines, was inevitably associated with the abandonment of coal pillars in the bowels of the earth: security (under buildings, structures, capital workings, etc.) and safety in preparatory workings (bremsbergen, inclined, near-track, interlace). Security cages in the process of exploitation of mines, as a rule, are not extracted, since their service life is very long, practically coincides with the service life of the mine. In addition, for their development, special methods of excavating and laying out the worked-out space are required. The safety pillars left in the process of exploitation can be referred to the category of operational losses by area. As the floor, horizon, pillar or field is worked through, they are removed, since the service time of the second type of pillars is determined by the period of operation of the preparatory excavations and does not exceed 3-5 years. In the preparation of certain measures, taking into account the safety of mining operations, these pillars can be partially or fully developed. In the CIS countries (Russia, Kazakhstan, Ukraine, etc.), there is a great deal of experience in extracting such pillars.

Further extensive development of the advanced technology of preparation and working out of the poles without leaving coal lobes in the developed space made it possible to solve such important technical tasks at the mines:

- ensuring normal conditions for the development of single and retinues of adjacent shock-hazard layers by preventing the development of centers of stress concentration in the mountain range;
- improvement of the conditions for the protective working off of the adjacent seams by eliminating the reference pressure zones that arise in the safety pillars;
- increasing the efficiency of ventilation and degassing of excavation sites as a result of the application of a straight-through ventilation scheme and flank wells;
- simplification of the network of preparatory workings and a reduction of more than 2 times the volume of tunneling work when cutting the poles;
- increasing the level of concentration of mining operations; decrease in operational losses of coal.

The expediency and effectiveness of the use of mechanized complexes for working off coal lobes from the main workings and developments in the main direction are limited to coal reserves of not less than 200-300 thousand tons. The development of the ends in the auxiliary excavations, as well as in the zones of geological disturbance at the outcrops of the seams with insignificant coal reserves methods and means of excavating the seams is considered generally ineffective.

In the Karaganda basin, the operational losses of coal are very significant, which is explained by the following circumstances: a large number of safety pillars along the preparatory excavations, left for the purpose of supporting preparatory workings; the abandoned sections of a complex configuration formed due to selective development of mechanized complexes only sites with favorable mining and geological conditions, off-balance reserves in areas adjacent to the outcrops of the seams, to zones of major tectonic disturbances, technical boundaries of mines, etc. So, for example, only for 1989 the loss of coal in the pillars amounted to 19.25 million tons (19.8%). A significant part of them (13%, or 6.65 million tons) accounted for losses in the security pillars.

Total losses on the basin since the beginning of working off the seams were about 40%. Of these, losses in area - 10%, in capacity - 9.3%, because of mining and geological conditions - 5.3% and mines for mining operations - 2.5%.

To those who received from the 70's. In the last century, the widespread use of clean mechanized complexes required a highly efficient operation due to the straightness and parallelism of conveyor and ventilation workings, which led to selective mining of mine fields under conditions of complex hypsometry. As a result, lavas of complex configuration were left between the lavas, having irregularly shaped polygons in plan.

According to the data on coal reserves in the whole complex, a total of 7 million tons of coal have been concentrated in the mines of the Tentek region since the beginning of their operation in the sections of complex configurations, with only the lakes on the upper, already worked out horizons being counted. Obviously, as the depth of development increases, these losses become even greater.

Large losses of coal are also observed in the Saransk area (12.6%, or 16.4 million tons) and in the Churuba-Nurinsk region (11.2%, or 6.9 million tons), where the layers also have complex mining-geological conditions (a dense network of geological disturbances, the presence of hard-to-collapse roof rocks, etc.).

2. Development and improvement of resource-saving technologies aimed at the development of coal seams in difficult conditions

Existing technologies require the constant presence of people in the face with unfavorable and dangerous to health conditions (dustiness, gas contamination, traumatic danger).

Thus, there is a major economic problem of increasing the efficiency of the coal mining process, improving the quality of the extracted products, freeing people from performing heavy manual labor in zones with unfavorable conditions, which indicates the relevance of research in this direction.

The introduction of resource-saving waste-free technologies for the extraction of coal seams on the basis of mining-robot mining is the most effective way to solve this problem.

The main shortcomings of existing technologies, including systems based on mountain combines, are high metal and energy capacity, low loading capacity, the presence of significant dynamic loads in kinematic connections, low mobility, as well as the high power-to-weight ratio of a combine harvester (over 1000 kV) Used for cutting coal while moving the combine along the entire length of the lava.

In most cases, the person or operator controls the mechanism or the robot at the command or movement level, while the operator needs continuous monitoring of the process, mechanism, robot, control and operational control of the entire system.

A possible way of eliminating the shortcomings of traditional mining technologies is the creation of systems that provide automatic gross and selective excavation, i.e. the creation of robot technology complexes for the extraction of coal seams without the constant presence of people in the bottomhole.

One of the priority directions of the concept of development of the mining industry of Kazakhstan for the period up to 2020 adopted by the Government of the Republic of Kazakhstan is robotization and automation of production processes, environmental safety and measures to reduce the negative impact on people of the environment.

The development of coal seams by underground means adversely affects the state of land resources and causes both ecological and socio-economic damage. The introduction of a non-waste technology for the extraction of coal seams requires the creation of scientific bases for mining robots, as well as the preparation of engineering designs for the elements, devices, control systems for mine robots.

The underground method of coal mining in the world over the past decades has undergone significant progressive changes and continues to maintain a development trend towards increasing production productivity through improved labor organization, a high level of integrated mechanization, automation and robotics.

Despite such a trend, at the coal mines of the Karaganda basin there is still a noticeable shortage of high-performance mining equipment; the cost of imported equipment is extremely high. The foreign investor of JSC "ArcelorMittal Temirtau" does not show much interest in further technical development and equipping of local coal mines.

At the same time, the continuous deterioration of the mining and geological and mining conditions of coal seams and their high gas content have a negative impact on the growth of labor productivity and the level of underground coal mining with the deepening of mining operations.

Over the years, underground coal mining in the Karaganda coal basin has sharply decreased, the number of coal mines has been reduced to a minimum. Reserves of coal on layers with favorable conditions of occurrence, naturally, decrease. But the demand for coal in the country, and indeed in the world, remains high.

In these conditions, the issue of careful and rational use of available natural resources re-emerges for the basin. This is especially true for underground coal deposits. In the old and in the fields of the operating mines of the Karaganda basin, hundreds of millions of tons of coal have been left for mining and geological and technological reasons in the form of various coal ends and local areas, which, due to limited size, complex configuration and inadequate conditions for their development, and traditional mining technologies, proved to be impossible or ineffective. The total coal reserves in these areas reach up to a quarter of the total reserves of the basin, moreover, with the growth of the depth of the development of coal seams, these losses will continue.

For this reason, one of the promising directions for reducing coal losses in the bowels of the earth and increasing the efficiency of coal mining may be work on involving in the total mine production reserves of local areas and sections of beds with complex conditions of occurrence by introducing technologies for excavating with short cleaning faces without carrying out preparatory workings using mobile excavating machines-manipulators and robot-technological complexes.

The purpose of the work is the development of scientific and technical fundamentals and technological parameters of non-traditional technology of coal mining by short cleaning faces without carrying out precast preparatory workings with reduction of assembly and dismantling works that ensure efficient development of local sections and sections of layers with complex development conditions.

At the same time, the increase in the efficiency of coal mining through the development of local areas based on the use of new technological schemes for the extraction of coal by short cleaning faces can be achieved due to the following factors:

- exclusion or reduction of costs for carrying out preparatory workings;
- reduction of installation and dismantling operations during transitions from one site to another;
- applications of small-length complexes, the cost of which is 3-4 orders of magnitude lower than conventional serial ones;
- selective and gross working out of coal seams, providing in aggregate reduction of the general losses of coal to 20-25%;
- reducing the cost of coal produced by 15-20%;
- preservation of ecological cleanliness of the environment and rational use of the earth's interior.

Previously achieved practical results in this direction:

- developed and researched parameters of technological schemes of front-flank-selective excavation using excavating machines-manipulators [1,2];
- developed a method for selecting and justifying the methods of selective processing of the face and determining the speed of their movement [1,2];
- developed variants of the technology for the transition of geological disturbances of the fault-reset type with amplitudes up to 2-3 m [1,2];
- developed specifications for the creation and development of production of robotic complexes for selective excavation [3,4,5].

In this direction, in Karaganda State Technical University in conjunction with the Eurasian National University (Republic of Kazakhstan), on the basis of previously conducted scientific and experimental work [1-4], the Terms of Reference were developed and the parameters of the coal seam removal technology and the main functional elements of the mining robotic complex with adaptive control software (MRCACS) [5,6,7].

3. Creation of a mining robot complex with adaptive control software

In order to reduce the loss of coal in local areas of coal seams, which are located in difficult conditions, and abandoned springs, taking into account the experience and results of earlier scientific and experimental works in the conditions of the Karaganda basin, in the development of this direction, work was carried out to create a mining robot complex with adaptive control software (MRCACS). The MRCACS complex is intended for development of local off-balance reserves of coal seams (for various purposes), lying in complex mining and geological conditions, with a length of lava up to 45-60 m. The complex can be used for selective excavation when working on gently sloping coal seams, structural structure, since the Navy-4NA is capable of conducting a layer selective excavation.

In the course of these works, the structures were selected and improved, the components of the complex, including excavating manipulators, were grounded and investigated. The structural scheme of the subsystems, regulated by the executive body when choosing the cutting method, has been worked out, the questions of designing the model of the elements of microcontroller control systems for technological processes, namely the control system of the robotic platform of the manipulator. The development of technical documentation, the production of a prototype and the production testing of the complex at one of the mines of Karaganda, in the course of which it is planned to conduct studies of the processes and methods of destruction of strong rocks, taking into account the dynamics of the interaction of external environments and the elastic properties of the links. The technology offers an innovative method of cutting coal in the bottomhole, which provides a reduction in the specific energy consumption of cutting the formation up to 10 times compared with existing harvesting combines. The total power of the excavator motor is about 50 kW.

Advantages of the technology are as follows: providing technology for coal mining with a minimum presence of workers due to the application of adaptive-program management complex; reduction of the specific energy intensity of the destruction of the mineral by the excavating machine; low metal intensity of the cleaning complex and a digging manipulator 2-3 times as compared to the existing means.

The introduction of robot technology complexes will increase the effectiveness of the interaction of the human operator and the diagnostic system of the treatment complex and minimize the danger to those working in underground coal mining. There is the possibility of a re-opening and development of technogenic reserves of mineral deposits in difficult mining and geological conditions.

Currently, in most cases, the management of mining excavation units and complexes is carried out by a human operator, which requires continuous monitoring of the technological process and operational management of the work process.

Such a situation is determined by the inability of aggregates and complexes to automatically adjust or modify the program of actions, to make decisions in cases of changing the technological situation (change in rock hardness, appearance of an empty rock zone), make independent decisions

In existing systems, it is necessary to organize and maintain the communication channel of the unit with the human operator.

When performing technological operations, the operator, receiving information about the control object and the technological process from the system, continuously monitors and controls the executive mechanisms of the entire complex. The complexity of the process, unfavorable conditions in combination with the nature of work requiring increased attention, leads to rapid fatigue of the operator and, as a result, an increase in the probability of erroneous actions.

However, despite the considerable development and wide application of the automated aggregates examined, it should be noted that existing systems do not have the ability to selectively excavate in conditions of reservoirs with complex hypsometry, with the presence of rock interlayers and solid inclusions, and geological disturbances that is typical for deposits of the Karaganda coal basin.

In the L.N. Gumilyov Eurasian National University (ENU) (RK, Astana) on the topic "Research and development of technology for an environmentally friendly mining robotic complex of selective on the basis of serial equipment (MRCACS)" a great scientific work was carried out. L.N. Gumilyov ENU and the Karaganda State Technical University (Karaganda) together with the UD of ArcelorMittal Temirtau JSC and Karaganda Engineering Consortium LLP conducted the development of the industrial and innovative project "The mining robot complex with adaptive control software (MRCACS)".

The greatest development of work on mine robotics and program management of technological processes was in the UK, Japan, the USA, Germany, the Czech Republic. For example, since 1995, the US has launched a wide application of robot manipulators for drilling holes (Fanuk firm), installations of concrete tubing support in tunnels (firm Dainiki). Robotization of mining operations in the UK is carried out within the framework of the state program.

The control system of the main support at the Ellallont mine (Australia) provides remote control for the following operations: unloading, moving and spreading the support sections, moving the conveyor, extending and retracting the flexible console. This system is based on the use of low-current electronic equipment in intrinsically safe design. The operator can unload, move and unlock the support sections, and also move the conveyor.

This control is carried out remotely within 25 securing sections on both sides of the currently controlled section.

The Raspadskaya mine of the Yuzhkuzbassugol Production Association (RF) tested remote and automated control of the support in the experimental sample of the KM138 complex, equipment for wireless remote control of the combine with an infrared channel of the UZM type, and the apparatus for regulating the formation hypsometry with the rock-coal sensor such as "Quantum III."

In the automated complexes KM-137A, KAM and KMC (for seams from 0.8 to 1.5 m), KM138A (from 1.2 to 2.5 m), ROS aggregates (for the seams from 0.65 to 0.9 m) and F-1, automation equipment was used from several independent or connected information systems, allowing automatic, remote and automated control modes of the support system to be controlled by the operator's commands. It was possible for the operator to change the order of movement of sections (sequential, chess), group sizes. The central panel reflected information about the state of the combine, conveyor, magnetic station.

Automated front-end combines (AFK) of the type CGS, KA, KAS were equipped with subsystems for tracking the "coal-breed" border, they have wireless radio or infrared control. The AFK unit is controlled from the control panel in the gangway.

The Institute "Donavtomatgormash" together with the mining association "EMAG" (Poland) created the means of automation of mining equipment: hydraulic and electrohydraulic actuators for automation of downhole equipment; A specialized microcomputer for installation on cleaning and tunneling combines; laser direction dial for mining operations and a control system for downhole equipment using infrared radiation.

The scientific research institutes and universities of Russia (Coal Institute of the Siberian Branch of the Russian Academy of Sciences, IGD named after AA Skochinskiy, MGI, Novocherkassk Polytechnic Institute), Ukraine (Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine) also engaged in questions of mine robotics, technology of unmanned excavation of very thin steep strata , Institute of Geological Sciences of the National Academy of Sciences of Ukraine).

Attempts to remove existing deficiencies have been made in the project to create robotic coal mining complexes without the constant presence of people in the ORKAPU cleaning face, which uses a microprocessor control system with automatic and remote control of the Navy excavator, a mechanized support and a main conveyor providing:

- automatic control of the manipulator by the given program;
- control of the mechanized support according to the set program;
- control of the reverse conveyor on the drift;
- management of bottomhole conveyor;
- control of the filling complex "Titan" (with selective excavation);
- automatic load regulation for different diameters of the cutter crowns of the Navy;
- change in the program of work of the complex, depending on mining and geological conditions;

- remote control of the manipulator and mechanized support;
- provision of necessary protections and interlocks.

The control system includes local control systems of the Navy and the support, the device for transmitting and receiving information, and a control device.

The microprocessor control system of the robotic complex for selective excavation is based on the CPU KR580IK80A, the interface circuit module is implemented on the 132 series chips, the programmable read-only memory on the BIS KT556RT5.

The trunk system allows connection of interface devices for automatic control of the complex. A set of such devices and corresponding to the various processing schemes for the face, the control program placed in the programmable memory module serves to conduct the operation of the complex in various modes of coal extraction, taking into account the formation hypsometry.

The aim of the work at this stage is the development and creation of a prototype of a robotic technology complex based on the Glinnik clearing complex (Poland), in which the mining tool for the front-line operation of the Navy-4NA (Figure 1 and Table 1) is used as the excavation tool and experimental research work capacity of the complex, as well as technological and other parameters.

The mining purification robot-technological complex [1-11], designed for the development of coal seams underground by unmanned coal mining technology, consists of the following modular and functional elements:

- mining excavator;
- equipment with an adaptive-programmed control unit with state diagnostics and actuators in the form of hydro stocks, hydraulic jacks with position indication when performing roofing fastening and management operations;
- mechanized support and excavating manipulator of the Navy all hydrostatic and hydraulic jacks, which are equipped with hydraulic cylinders with position indication, they serve as actuators;
- scraper face conveyor, with vertically arranged scrapers on the curvilinear section for the withdrawal of the Navy in case of failure of functional elements;
- electrohydraulic equipment.

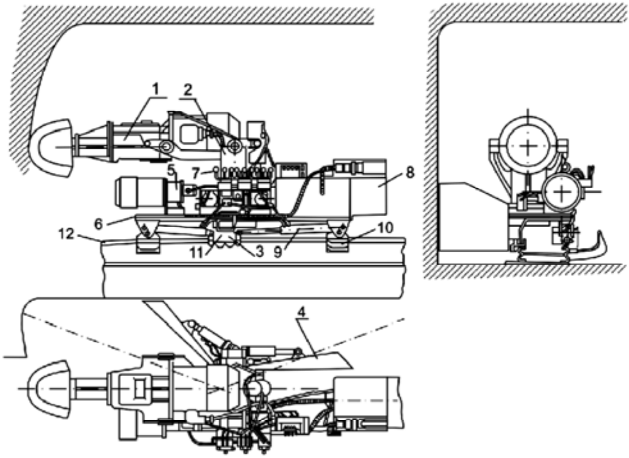


Fig. 1. The excavating machine-manipulator VMF-4HA: 1 – arrowed executive; 2 – pivoting device; 3 - movement mechanism; 4 – loading device; 5 - electric motor with oil station; - 6 - frame; 7- the control panel; 8 - magnetic station; 9 - support-feeding mechanism for the capture of feed jacks; 10 - downhole ski; 11 - hydraulic gripping; 12 - round guide

Table 1

Technical characteristics of the Navy

№	Indicators	Values
1	Removable bed thickness, m	3,0-5,0
2	The amount of grip, m	0,5-0,8
3	Productivity, t / min:	
4	-with manual control	3,0
5	-with automatic control	4,0
6	The angle of incidence of the formation, deg.	9-35
7	Feeding force, N	10-15
8	Feeding speed, m / min	to 10
9	Type of movement mechanism	Bezeless, walking
10	Type of executive body	Arrow with incisor crown
11	Specific energy intensity, kW · h / t	0,25
12	The power of the executive body on the basis of a pass-through harvester PK-56M, kW	46
13	Dimensions. mm: -length by base	4000
14	-width	1350
15	-height	5000

The control system of the robot-technological complex is a set of the following modular devices: an automatic extractor arm of the Navy type, a mechanized support, a scraper conveyor and other equipment that register incoming signals in the control unit of the DAC via pressure sensors and a magnet for indicating the flow of liquid and temperature [5-10].

The control system of the robot technology complex is shown in Fig. 2. All signals from the digital analog converter are processed in the form of digital values of the computer with software, from there, in the form of digital signal values, to the actuators. The sensor signals are sequentially transmitted to the DAC, from there they are converted as necessary signals to the actuators, the hydraulic distributor and the control electro-valve (ECU), which are then fed to control all processes and operations for coal mining in the bottom face, and also to all hydro stocks and hydraulic jacks position indication according to the software.

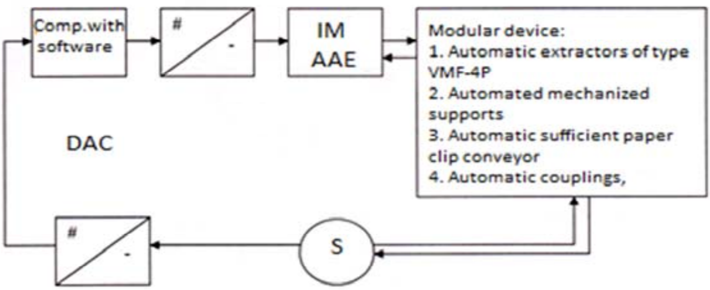


Fig. 2. Block diagram of module control: IM AAE - actuator and control electrovalve; DAC - digital-to-analog converter; S– sensor

During the creation of the complex it is supposed to conduct research of processes and methods of destruction of strong rocks taking into account the dynamics of external environments and elastic properties of links, optimization of parameters of electrohydraulic actuators of executive manipulation mechanisms with walking moving systems of various degrees of mobility, development of adaptive-program management in interactive mode and complex management system (Figure 3) and the system for diagnosing the states of the components of the treatment complex, modeling the dynamics and actuators, taking into account non-linear functions of the position when cutting hard rock and other issues.

The device (figure 3) works as follows. From the control panel, the hydraulic pumps 8-10 of the motor 16 of the operating element are switched on via the control unit, the distributors 13-18 are all switched to the left position L. Thanks to the pressure of the control pump 10 and the distributors 13, 14 and 18, the distributors 11, 12 and 19, respectively hydraulic control in the right position II. From the working pump 8, the pressurized liquid is supplied to the rod cavities, the hydraulic clamp 7, and it engages the guide 21 of the conveyor with curved portions, simultaneously through the distributor 11 the liquid is supplied to the piston cavity of the hydraulic clamp 6 and it disengages from the guide 21. From the working pump 8 the liquid under pressure through the pressure line 20 through the distributor 12 on the right and the line 22 is fed into the piston cavity of the hydraulic cylinder 5. There is a supply of the Navy to the face and at the same time the liquid is distilled and rod end of the hydraulic cylinder 5, the rod end of the hydraulic cylinder 4, which causes the preparation of the hydraulic cylinder 4 and hydraulic dual 6 for the next cycle of operation. The position sensors of the hydraulic cylinders 4 and 5, with full retraction of the rods, switch the diributors 13 and 14, which in turn switch the distributors 11 and 12. The hydraulic clamp 6 engages with the guide 21, and the hydraulic cylinder 4 delivers the Navy to the bottom. The liquid from the rod cavity of the hydraulic cylinder 4 passes into the hydraulic cylinder 5, which causes the preparation of the hydraulic clamping 7 and the hydraulic cylinder 5 to the next cycle of operation for the selection of the coal breakage scheme. So the process of switching is repeated, and there is a continuous supply of the Navy to the face. The speed of moving the Navy depends on the performance of the working pump 8, and also on the motor load of the actuator 16.

Simultaneously, from the working pump 8 via the line 24 through the distributor 19 on the right side, the liquid is supplied to the piston cavity of the hydraulic cylinder 3, which causes the working member to move downward. When the operating body reaches its lowest position by means of jack sensors through the control unit, the distributor 18 switches, which in turn causes switching of the distributor 19. The liquid from the working pump 8 is fed through the distributor 19 in the left position into the rod cavity of the hydraulic cylinder 3, which causes the working member to move bottom up, then the cycle repeats.

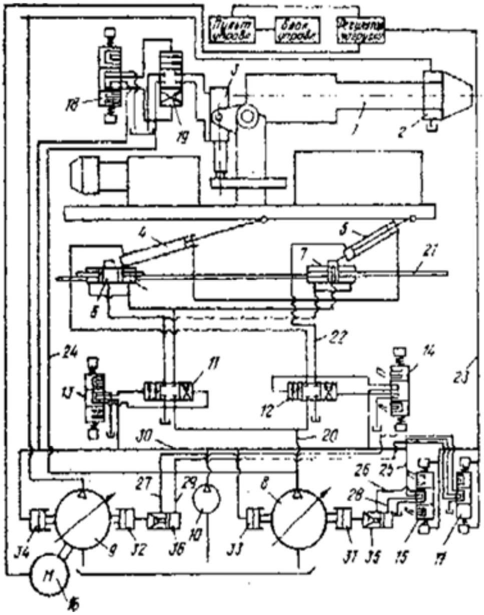


Fig. 3. Block diagram of mining excavation control of VMF

The speed of movement of the working member also depends on the load of the motor 16 of the actuator, from the control panel via the load controller via the cable 23 of the distributors 15 and 17 are simultaneously switched to the left position. From the control pump 10, liquid is flowed through the main line 25, through the distributors 15 and 17 to the left position through the lines 26 and 27, through the hydraulic locks 35 and 36, under the trunnions 31 and 32, which causes the stators of the regulated pumps 8 and 9 to move simultaneously. Moving the stators causes the task the specific productivity of the pumps 8 and 9, and consequently, the setting of the feed speed of the combine, the speed of the boom and the speed of rotation of the hydraulic motor of the working element, while retaining VP / Vn = const., where Vn is the feed speed of the combine, VP is the speed of rotation of the hydro drive the working body

With technological overloads or to maintain the rated load of the motor 16 of the working element, the signal is fed to the load controller by means of current sensors, the processed signal is applied to the distributor 15 and cable 17. The distributors 15 and 17 are switched to the right-hand position of P from this signal, pump 10 liquid through the main 25 through the distributors 15 and 17 on the right, along the lines 28 and 29 is fed into the piston cavities of the hydraulic locks 35 and 36, which causes them to open. Due to the pressure of the liquid from the pump 10, through the trunk 30 to the pins 33 and 34, and due to the brief drainage of the liquid from the trunnions 31 and 32 through the hydraulic locks 35 and 36, through the manifolds 26 and 27 and through the distributors 15 and 17, the stators of the pumps 8 and 9, which causes a proportional decrease in the productivity of pumps 8 and 9, which in turn causes a reduction in the feed rate of the Navy, the speed of rotation of the hydraulic motor of the working element, or the load current of the motor 16, with the ratio Vp / Vn = const.

Thus, the use of the described device, designed as an invention [11], ensures the operation of the combine in the optimal mode, taking into account the output in the event of failure of the functional element of the Navy APU through the curved section of the conveyor. The total number of Navy on the downhole conveyor can be up to 8-10 if, due to the failures of the Navy, it goes under the support section to 9 Navy, which provides increased productivity in the bottom hole due to their reliability and reliability of the technology of coal mining. The recommended technology provides from 6 to 12 thousand tons per day of coal from a single bottom face

For the complex control equipment, the applicability factor should be at least 75%.

The name and purpose of the components of the control equipment are given in Table 2.

Figure 4 shows a block diagram of the proposed microprocessor control system for the VMF-4HA retrieval manipulator [5,7] and a general view of the automatic control system of the working body by the extracting robot manipulator and the algorithm of its operation - realizing the control of the selective action of the mining machine, scheme of the algorithm for determining the coordinates of laser beam points on the tail and knife screens of the photodetector device.

Table 2

Components of control equipment

Name	Quantity	Appointment
1	2	3
The control manipulator manipulator	1	Automatic and remote control of the mechanism of movement of the executive body and the mechanism for moving the manipulator. Automatic load control of the manipulator. Remote control of face-to-face mechanisms, providing loudspeaker communication over lava and warning signaling before the inclusion of downhole mechanisms
Instrument for controlling the support	1	Automatic and remote control of securing sections
Equipment for transmitting and receiving information	1	Receiving information from the control device installed on the drift. Storage and transmission of information to the control device
Control device	1	Generation of signals for control of the manipulator and the support. Reception of information specifying the work of the extracting machine-manipulator and crepe according to the program
Control equipment for the reversible drift conveyor and forage-crushing equipment	1	Automatic and remote control depending on the technological mode of operation

The presented control system consists of an optical directional setting device - laser, diaphragm, photodetector device, interface module, position sensors of each degree of mobility of the working element, a roll sensor, electrohydrozolotonics control units and a computing device. The photoreceiver consists of a semitransparent mirror, which is located at an angle of 45 ° to the longitudinal axis of the device body, two screens - a tail and a knife - with zero marks and two video modules. The tail screen is located above the reflective surface of the semitransparent mirror so that it is parallel to the longitudinal axis of the device, and the knife screen is at a distance behind the non-reflecting surface and perpendicular to the longitudinal axis. Each video module is located behind the corresponding screen at the focal length of the lens.

The control manipulator control system (Fig. 4) consists of the following consecutive parts: a laser 1 optically coupled through a diaphragm 2 with a photodetector device 3 whose output is electrically connected to a computing device 4 with which position sensors 6, 7, 8 are connected via an interface module 5 of each degree of mobility of the working part 9 of the cleaning complex 10, a roll sensor 11 and control units 12, 13, 14 with electrohydrohydrozolics. And the photodetector device consists of a semitransparent mirror 15 installed in the device body 3 on the side of the laser setting device 1 located at an angle of 45 ° to the longitudinal axis of the same device, two screens - a tail 16 and a knife 17 - with zero marks and two video modules 18 and 19. Here, the tail screen 16 is located above the reflective surface of the semitransparent mirror 15 so that it is parallel to the longitudinal axis, and the knife screen 17 is about 1 m behind the non-reflecting surface and perpendicular to the longitudinal axis of the device 3.

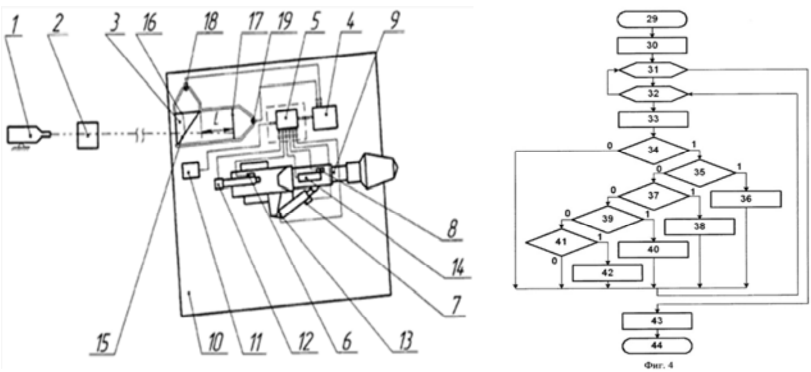


Fig. 4. Automatic control system for excavating robot manipulator

Each video The module 18 and 19 is set for the corresponding screen on the focal length of the lens of the video module. Laser 1 and diaphragm 2 are installed in the tunnel, and all other blocks are installed in the mining complex. The block diagram of the program algorithm implementing the operation of the selective-action operating element 9 consists of the program start block 20, the scale factor input unit 21, the color of the laser beam, the geometric dimensions of the working member, the values of the one-sided broadening of the mine workings, the unit for determining the coordinates of the points of intersection of the reflected and past without changing the parts of the laser beam 22 with tail and knife screens, respectively, the coordinate determination unit of the mining and drilling complex 23 in space, the coo detection unit a unit for determining the coordinates of the reference points 25, a control output unit for the hydraulic cylinders of each degree of mobility 26, a control unit for controlling the movement of the complex 27, a control unit for driving the drive mechanism of the complex 28. The information is processed in the computer 4 .

The block diagram of the proposed microprocessor control system for the manipulator is given in Figure 5

The microprocessor AVR 32-bit, manufactured by Atmel (Figure 6), was built using the advanced RISC architecture of the AVR. Performing one command for the period of the clock frequency, AVR 32-bit has a high performance of about 66 MHz.

The tasks that can be achieved to achieve the final result: ensuring the safety of mining operations in the face, conducted without the constant presence of workers through the use of adaptive-program management; a sharp decrease in losses of minerals, an increase in the quality of mined mineral due to the use of a mining automatic manipulator with an executive organ of selective action; a decrease in the specific energy intensity of the fracture of the mineral by the excavating machine and the metal consumption is 2-3 times that of the existing narrow-cut harvesters.

The project proposes an innovative method of cutting coal in the bottom hole [5-7,12], which provides a reduction in the specific energy consumption of cutting the formation up to 10 times compared with existing harvesting combines. The total power of the excavator motor is about 50 kW. This is achieved by the fact that when the rock is cut off by the sweeps of the executive bodies of the combines, which is the supply of the executive body to the face, the rocking of the executive body along the thickness of the formation and the movement of the executive body are carried out simultaneously (Figure 7)

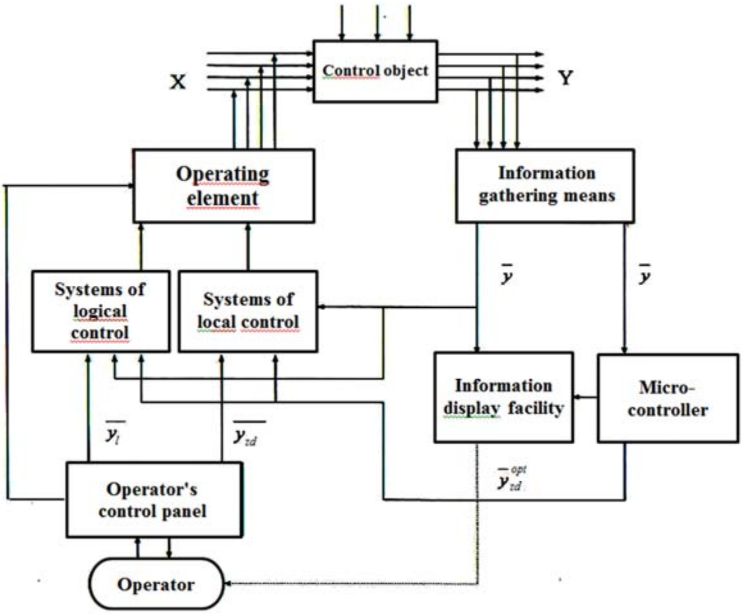


Fig. 5. Block diagram of the proposed microprocessor control system for the manipulator

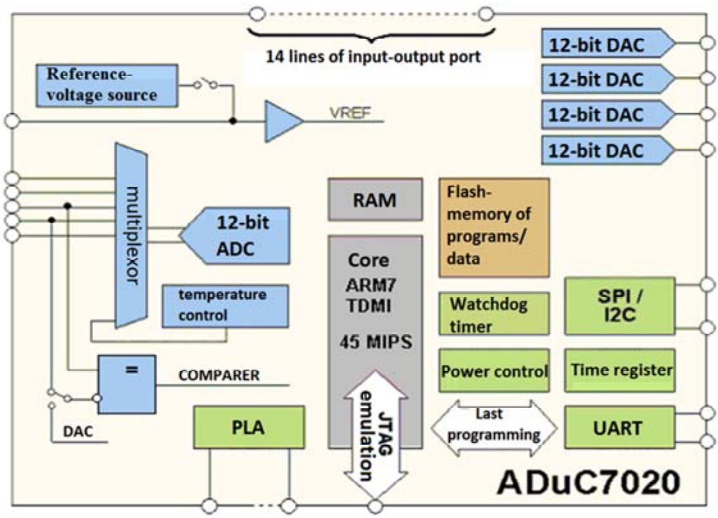


Fig. 6. Functional diagram of the microcontroller

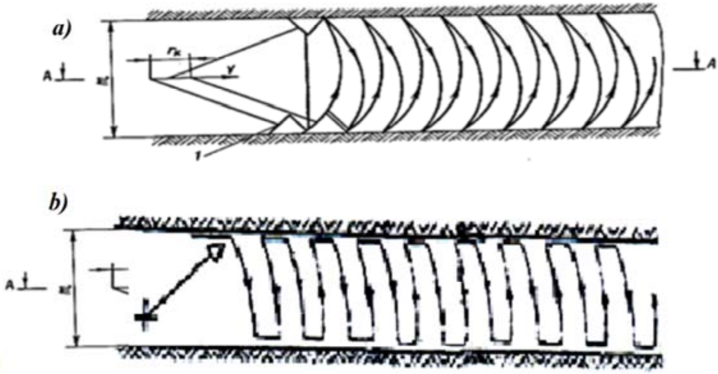


Fig. 7. Methods of processing the face by the executive body of the extractor: a) continuous method; b) a sequential method

The method for breaking rocks with arrowheads of the combine is carried out as follows: the bouncing element 1 with the crown 2 and the handle 3 hingedly mounted on the Navy 4, moving along the conveyor belt 5, produces a rocking out of the array by swinging the executive body along the thickness of the formation m with simultaneous continuous movement along the line of the face.

When breaking, symmetrical crescent shavings are obtained. During the breakage of two adjacent chips, the actuator performs a radial motion from the soil to the roof, from the roof to the soil, and the translational motion is the length equal to the capture of the bark bit along the line of the extraction face. In this case, the bark bit extends the path obtained by adding two movements: radial in thickness of the formation and translational along the line of the face with the trajectory and directions indicated by the arrows.

The proposed breaking-off method, carried out by extractors of the Navy type, ensures the continuity of the excavation work by the sweep type of the swept type, while the energy consumption is reduced by eliminating the direct introduction of the drilling tool in the array, which allows to distribute the electric costs for cutting at different points of the cleaning lava, and the existing cleaning of the power fluctuations more than 1000 kW and a mass of more than 100 tons ensure the cutting of the formation at one point of movement along the cleaning lava.

Extracting machines-manipulators have passed a multi- stage of development, since 70-80th years of the last century with participation of the author of this work. At one time, various modifications of mining excavating machines-manipulators were developed and tested in the mining conditions of the Karaganda basin (the Dolinskaya mine - twice, Toparskaya), Navy-2, Navy-4, Navy-4H (4M), Navy-4KN [1,2].

Figures 8 and 9 show the construction of the excavating machine-manipulators of the Navy:

- Navy-2 is designed for operation on shallow seams and has manual control;
- Navy-4KN designed for the development of steep-angle coal seams and has a remote control.
- Navy -4H(M) is designed for working on inclined reservoirs with continuous breakage of useful minerals.

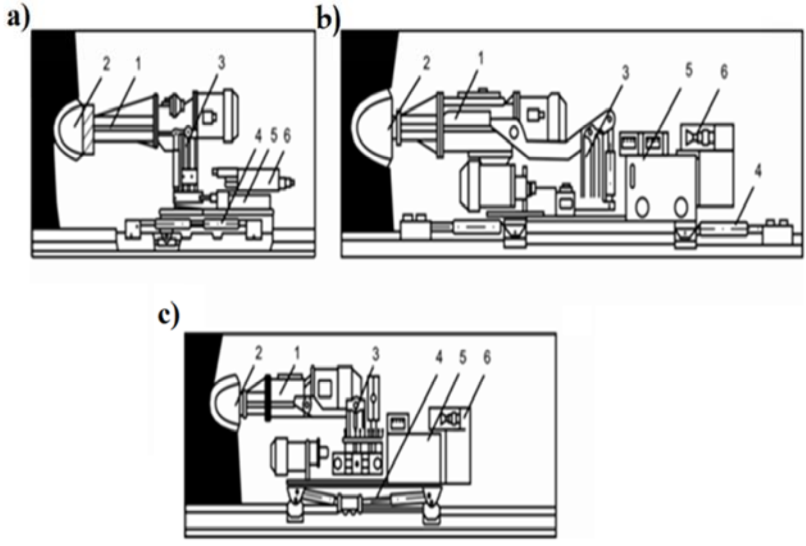


Fig. 8. Construction of excavating manipulators:
a) Navy-2; b) Navy-4KN; c) Navap-4H (M).
1 – an arrow with a reducer and an electric motor; 2 - incisor crown;
3 - turret for lifting and lowering the rotation of the boom; 4 - feeding mechanism;
5 - oil tank; 6 - magnetic station for control

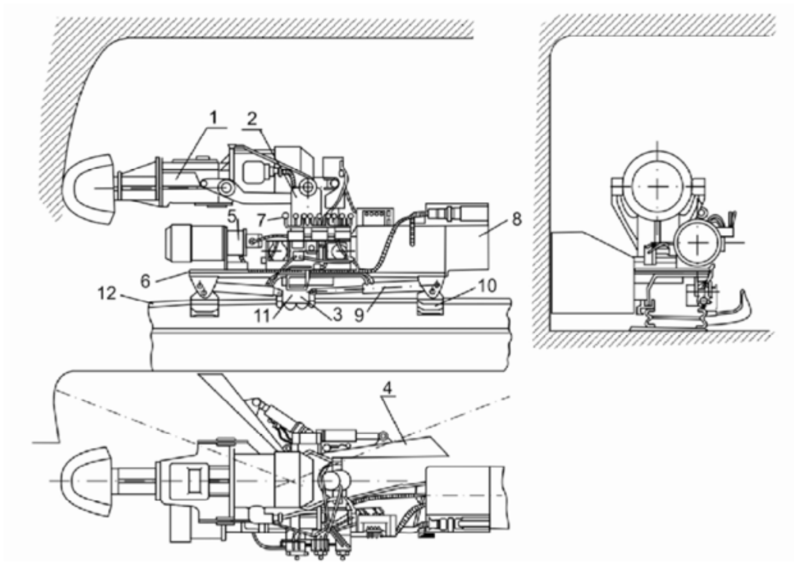


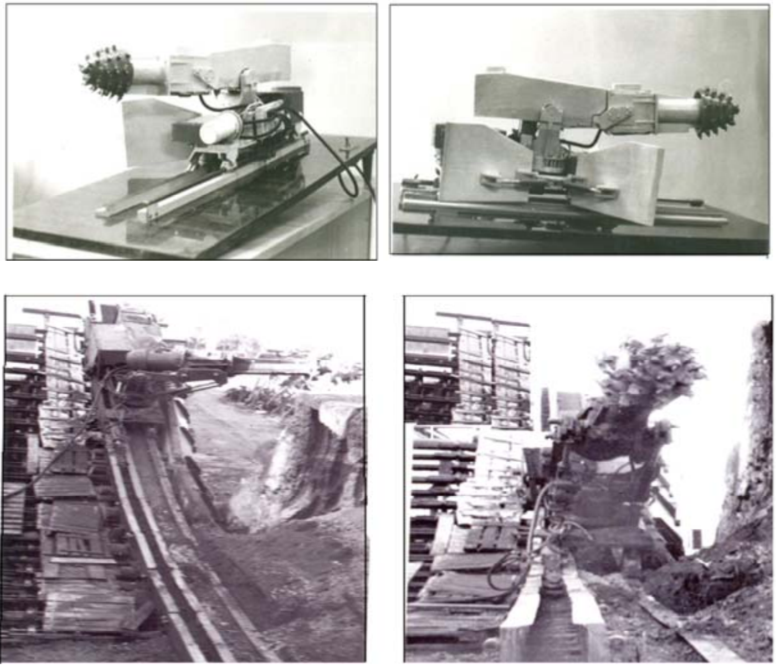
Fig. 9. Front end flanking machine VMF-4M:
1- executive body of selective action; 2 - turning device around the vertical axis by 180º; 3 - support-feeding mechanism of movement; 4-loading device; 5 -oil station; 6 - frame;7- the control panel; 8 - magnetic station; 9 - support-feeding mechanism for the capture of feed jacks; 10 - downhole ski; 11 -hydraulic gripping; 12 - round guide

The excavating manipulators of the Navy type underwent bench, mine acceptance tests with their subsequent introduction in the conditions of the mines "Toparskaya", "Dolinskaya", "Kazakhstan", after Kostenko and after Lenin.

In the course of continuous mine and bench tests, the performance of various options for installing the Navy in lava was proved.

The general types of experimental and industrial samples of a mining automatic excavator are shown in Figure 10

The brief overview of the most characteristic variants of mining excavators shows that the main drawbacks of the designs of these actuating mechanisms are low loading capacity, the presence of significant dynamic loads in kinematic connections, low mobility (displacement), and so on.



a)

b)

Fig. 10. General view of the manipulator:
a) general view of the experimental sample; b) general view of industrial design

The main advantages of the projected complex are:

- automatic control of the manipulator and the mechanized support according to the program;
- control of the downhole and reverse conveyor on the drift, laying complex (with selective excavation);
- automatic load regulation for different diameters of the incisors of the manipulator;
- change of the program of work of the complex, depending on mining and geological conditions.

The adaptive-programmed control (APC) of the MRCACS includes the following:

- the general scheme of microprocessor control;
- scheme of electric distributor with ferrites on 22 positions;
- general control scheme for the VMF-4HA excavator;

- hydraulic scheme of automatic control of Navy-4HA;
- hydraulic scheme of the sections of the mechanized support;
- the general scheme of the microprocessor, consisting of the hydraulic section control scheme and the control scheme of the mechanized support.

The area of application of the MRCACS complex is local off-balance reserves of coal seams (various purposes), as well as coal seams, which lie in complex mining and geological conditions, with a lava length of up to 45-60 m. The complex can also be used for selective excavation when working along gentle, inclined coal seams, having a complex structure, since the Navy-4NA is capable of conducting a layer selective excavation.

The development of robot-technological complexes will increase the effectiveness of interaction between the human operator and the diagnostic system and minimize the danger of emergencies. There is the possibility of a re-opening and development of techno genic reserves of mineral deposits in difficult mining and geological conditions.

Expected results:

- possibility of optimizing the characteristics of drives and mechanisms with walking moving systems in different degrees of mobility;
- automation of the design of manipulative "Robot" in various technological operations in conditions dangerous to human life and health;
- formation of technological and technical concept of construction of diagnostic and manipulation systems on the basis of directional study of mechatronics;
-high maneuverability of the execution of operations by various options, depending on the location of the Navy-4A;
- possibility of adaptive-program management of the complex at a considerable distance and even from the surface;
- ensuring high reliability and efficient operation of the complex in the cleaning face.

The implementation of the project on the use of the MRCACS complex [5-8] will ensure the protection and significant improvement of the state of the resources, that is: exclude the violation and damage to the land of the mining allotment; will eliminate the need to use land for dumps with the elimination of all negative environmental consequences.

In the course of scientific and experimental trials and research will be the parameters of the rock movement, the technological parameters of the coal seam removal technology and the main functional elements of the MRCACS complex, are proved, which allow: - to reduce the specific energy intensity of the destruction of coal and metal consumption by 3 times; to increase the safety of work by automating and robotizing coal excavation on the basis of unification, condition and fault diagnosis, microprogram control using microprocessor means; improve the environmental situation in the region (by leaving the rock) and reduce coal losses, improve the quality and productivity of coal mining.

The final goal of the development is the introduction of MRCACS in the mine conditions of the JSC "ArcelorMittal Temirtau" UD [5,6].

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USES OF STATISTICAL INDICATORS TO ASSESS THE INFLUENCE OF ROCK PRESSURE IN THE PREPARATORY WORKINGS OF COAL MINES

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Abstract

At the present time, coal seams are worked out at mines up to 1000 meters and more. The increase in the depth of development causes the growth of the existing stresses and deformations of the enclosing rocks in the course of cleaning and preparatory work.

The observations made earlier show that along the length of the preparatory excavations in the zone of influence of the cleaning works, the values of the rock displacements on the contour have a considerable scatter. Displacements of the contour of the preparation workings often exceed the compliance of the three- and five-link arched flexible supports (AFS).

A large number of scientists in the field of mining dealt with the study of the regularities of manifestations of rock pressure. These studies formed the basis for many progressive solutions and made it possible to use methods of controlling rock pressure more justifiably. However, large volumes of repair and reinforcement of preparatory workings, in particular precincts, continue to increase.

The refinement of the geomechanical picture of the interaction of a layered massif of host rocks with the AFS of preparatory excavations, the determination of the zones of influence of the supporting rock pressure and the justification of the criteria for their evaluation are an actual task.

The main measurement procedure for the manifestation of rock pressure is taken as the measurement of subsidence in the links of the arched flexible supports from two sides and the measurement of changes in the displacement of the "upper" relative to the middle line of the metal arch support.

Analysis of studies of the manifestations of rock pressure

In general, preparatory mining can undergo the manifestation of rock pressure in the following zones:

- outside the zone of influence of clearing works and worked out space;
- in the zone of influence of clearing works ahead of the lava;
- in the area of influence of the cleaning works behind the lava during the initial use of the mine;
- in the area of influence of clearing works ahead of the lava in the repeated use of the mine;
- in the area of influence of clearing works behind the second lava.

Great importance on the deformation of the rock mass is provided by the type of support and the technology of its erection. In a number of cases, the support can lead to a change in the type of deformation of rocks.

The size of the reference pressure zone, according to many scientists, is also determined by the size of the span of the console, hanging over the space produced. As far as the movement of the face of the lava moves, the length of the hanging consoles will increase, and consequently, the pressure bearing zone and the loads on the surrounding rocks will grow. After breaking the console, the dimensions and intensity of the reference pressure zone will be minimal.

Changing in space and time, the zone of increased rock pressure will move ahead (behind) the face of the lava. This zone is of temporary reference pressure. In the future, there may be a partial collapse of the suspended console of the main roof or the console, gradually sinking, will find support on collapsed rocks in the worked out space. As a result, the pressure on the preparatory mine will gradually decrease, the deformation of the formation and rocks will stabilize. This zone is the residual reference pressure.

The studies are of A.A. Borisov, S.M. Lipkovich, N.A. Bazhin, Yu.I. Burchakov [1, 2, 3, 4] and other authors show that the reference pressure can be divided into two constituent parts:

- dynamic, associated with the work of the working face and changing periodically as it moves as the length of the cantilevers of the rock layers of the roof increases and decreases;
- static, associated with the lowering (deflection) of an array of rocks without delamination.

Due to the difference in causes that cause each of the two components of the reference pressure, the controls can also be different.

Modern concepts of the reference pressure are consistent with the hypothesis of a pressure wave. According to this hypothesis, damped pressure waves of the second, third and higher orders, caused by the cantilever effect of the roof of the formation, take place in the reference pressure zone. This phenomenon was established by G. Weber, O. Nemchik, G. Rieter as a result of surveying measurements [5].

The reference pressure zone, in front of the lava, has two different zones. The first zone is connected with the front fifth of the arch moving along with the lava. Within this zone, a zone of temporary reference pressure is formed in front of the lava. Temporary reference pressure depends on the composition of the rock mass and the depth of development, while the reference pressure associated with the fifth arch depends on the depth of development and, to a greater extent, on the working area.

At a greater distance from the lava, only the stationary reference pressure acts.

The uneven wave character of rock displacements in the zone of reference pressure is evidenced by various mine and laboratory studies.

Thus, researchers note two components of the reference pressure:

- the console of the rocks of the main and immediate roof, hanging over the worked out space;

- the sum of the bending moments of rocks that hang to the surface.

Analysis of the conducted studies shows that the difference in displacement along the length of the production is a consequence of the periodic nature of the manifestations of rock pressure. At the same time, it was established in the works of I.L. Chernyak and V.F. Cherkasov [6, 7, 8] that the amplitude of the displacements in magnitude is close to the mean value with a confidence interval of the double standard deviation. The periodic nature is approximated by the sinusoidal equation, and the amplitude appearing in this equation was compared with the standard deviation. Continuation of studies of dynamic reference pressure was the work of I.L. Chernyak and Yu. F. Fomin [9, 10, 11, 12, 13]. It was found that the unrecognized share of displacements is the result of exposure to less significant layers of the roof. A technique was developed that determines the influence of several layers of roof rocks on the displacement of the contour of the preparatory workings. For this displacement of the roof rocks along the length of the drift were approximated by a trigonometric polynomial.

Application for processing the results of instrumental observations of Fourier harmonic analysis made it possible to determine the amplitude of the displacements and the period (step) of the collapse of various layers of rocks of the immediate and main roof, as well as the fractional participation of each significant layer in the total amplitude of the displacements. The analysis of the results of the manifestations of rock pressure in preparatory workings allows us to draw the following conclusions:

- preparatory development in the area of influence of clearing operations along with the static reference pressure is affected by the dynamic reference pressure, which has a periodic character, which is a consequence of the process of formation, hanging and collapse of rock layers in the worked-out space;
- the characteristics of the periodic manifestations of the

reference pressure are the period (step) of the collapse of the rock consoles, as well as the maximum amplitude (range) of the values of the rock displacements created by the dynamic component of the reference pressure;

- to develop recommendations for the maintenance and reuse of precincts in the areas of influence of rock pressure, one should know the parameters of the magnitude of the influence of static and dynamic components;
- the period of change in the amplitude of the displacement along the mine depends on the properties, composition, and structure of the rock massif of the depth of development, as well as on the location of the considered area of development with respect to the worked out space and methods of protection.

The results of instrumental mine observations

The field observations were carried out in conditions of layer h_8 of the “Progress” mine, PA Torezanthracite, preparation method - horizon. Observations were carried out in the 2nd sidewalk, traversed by the formation during the development of the formation with the use of a combined development system. The guard of the onboard walker was made with 4 m long coal and 5 m with a stripe. Cleaning operations were carried out with the help of the mechanized complex KM-88 with the combine 1GSH-68. The thickness of the layer h_8 within the boundaries of the experimental plot was 1.26 ... .1.43 m. The strength of the coal was two (according to M.M. Protodyakonov). The angle of incidence of the formation is 4 ... 5 °. The brand of coal is anthracite. The immediate roof is represented by sandy-argillaceous shale with a thickness of 1.5 ... 3.0 m with a strength of f = 5 ... 6. In the main roof there was sandy-argillaceous and sandy shale with a thickness of 7.0 ... .13.5 m and a strength of f = 8 ... 9. The depth of the embankment laying did not exceed 1200 m (Fig. 1, Fig. 2). The measuring areas were located on the second side run of 100 m long. The first in 50 m from the installation furnace is the second one at 30 from the first drop in the formation.

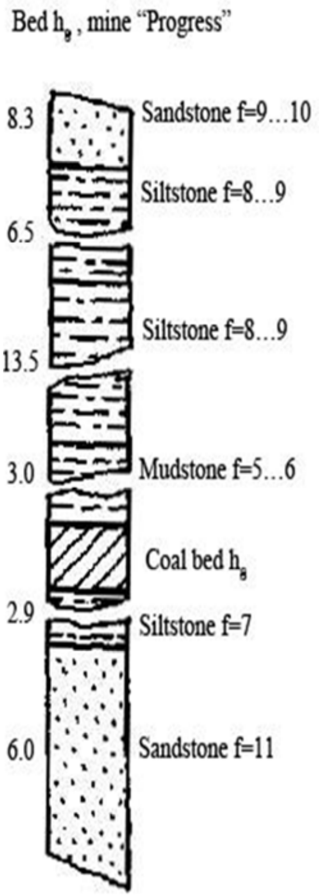

Fig. 1. Excavation from a mining plan

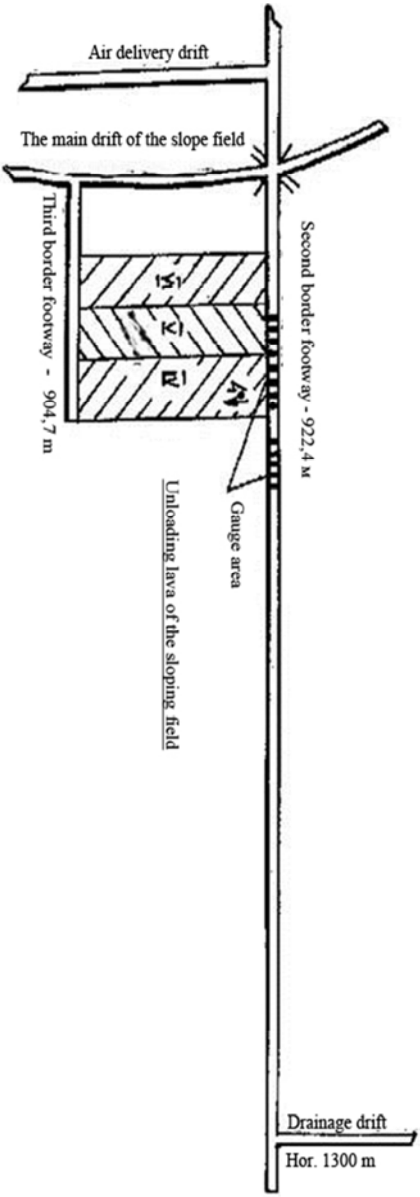

Fig. 2. Mining and geological conditions

The results of statistical processing of instrumental mine observations are given in Table 1 and Table 2.

Table 1

Statistical indicators of the results of displacement measurements on the contour of the preparatory development in the conditions of the h_8 formation (when leaving the assembly furnace)

from the coal mass side									
L, м	*Umax*	*Umin*	*Δ U*	*Ucp*	*Ud*	*M*	*σ*	*V, %*	*t*
1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
-10	267	0	276	79.00	100.00	138.00	53.00	67.00	9.31
-5	364	10	354	96.00	97.00	187.00	63.00	66.00	12.10
0	382	20	362	123.00	95.00	201.00	74.00	60.00	8.81
5	430	20	410	152.00	95.00	225.00	92.00	60.00	6.64
10	520	20	500	175.00	95.00	270.00	108.00	82.00	7.36
15	632	30	490	190.00	94.00	275.00	114.00	59.00	6.24
20	640	34	598	209.00	95.00	333.00	133.00	64.00	7.80
25	640	40	600	228.00	94.00	340.00	138.00	60.00	8.80
30	645	50	590	229.00	92.00	345.00	133.00	58.00	6.80
35	650	50	595	230.00	92.00	347.00	132.00	57.00	6.60
40	670	50	600	232.00	92.00	350.00	130.00	57.00	6.50
45	670	50	620	232.00	92.00	360.00	131.00	56.00	6.60
50	690	80	610	254.00	88.00	385.00	130.00	56.00	6.30
55	710	100	610	265.00	86.00	405.00	127.00	54.00	6.50
60	710	110	600	286.00	85.00	410.00	128.00	54.00	5.30
65	730	140	590	288.00	81.00	435.00	127.00	53.00	5.80
from lava side									
-10	249	0	249	64.90	100.00	125.00	46.60	72.00	10.70
-5	270	0	270	78.20	100.00	135.00	51.60	66.00	9.21
0	290	7	283	95.20	98.00	149.00	55.30	58.00	8.06
5	314	10	304	115.00	98.00	162.00	61.90	54.00	6.35
10	332	10	322	139.00	97.00	171.00	68.00	49.00	3.94
15	382	10	372	165.00	97.00	196.00	81.90	49.00	3.17
20	444	17	427	192.00	96.00	231.00	90.70	47.00	3.59
25	448	20	428	216.00	96.00	234.00	98.70	46.00	1.47
30	510	30	480	235.00	94.00	270.00	112.00	48.00	2.42
35	515	30	485	271.00	94.00	273.00	115.00	42.00	0.13
40	519	40	479	293.00	92.00	279.00	119.00	41.00	0.83
45	520	40	480	300.00	92.00	280.00	123.00	41.00	1.10
50	523	50	473	310.00	90.00	287.00	124.00	40.00	1.17

Table 1 continuation

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
55	526	70	456	318.00	87.00	298.00	123.00	39.00	0.96
60	529	80	446	320.00	84.00	305.00	124.00	39.00	0.66
65	531	100	431	340.00	81.00	316.00	124.00	36.00	0.96
offset of the upper point									
-10	335	0	335	118.00	100.00	168.00	65.20	55.00	6.40
-5	340	0	340	138.00	100.00	170.00	63.80	46.00	4.19
0	345	0	345	157.00	100.00	173.00	67.50	43.00	1.98
5	350	26	324	178.00	93.00	188.00	70.00	39.00	1.19
10	360	38	322	191.00	89.00	199.00	75.00	39.00	0.89
15	366	60	306	215.00	84.00	213.00	72.00	34.00	0.23
20	367	75	292	226.00	79.00	221.00	71.00	32.00	0.59
25	366	80	306	238.00	79.00	233.00	73.00	31.00	0.55
30	401	90	311	243.00	78.00	246.00	73.00	30.00	0.32
35	410	90	320	255.00	78.00	250.00	76.20	30.00	0.48
40	428	90	338	265.00	79.00	259.00	74.00	28.00	0.57
45	434	99	335	267.00	77.00	267.00	73.00	27.00	0.00
50	439	100	339	278.00	77.00	269.00	73.70	26.00	0.82
55	440	100	340	280.00	77.00	270.00	81.40	20.00	0.73
60	448	117	331	283.00	74.00	283.00	81.70	29.00	0.00
65	458	130	328	311.00	72.00	294.00	78.40	25.00	1.10

Table 2

Statistical indicators of the results of displacement measurements on the contour of the preparatory mine in the conditions of the reservoir h_8 (with steady collapse mode)

from the coal mass side									
L, м	*Umax*	*Umin*	*Δ U*	*Ucp*	*Ud*	*M*	*σ*	*V, %*	*t*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
-10	140	0	140	38.00	100.00	70.00	32.00	84.00	8.06
-5	195	0	195	50.00	100.00	97.50	40.20	80.00	9.53
0	310	0	310	80.00	100.00	155.00	68.50	83.00	9.10
5	460	0	460	125.00	100.00	230.00	101.00	81.00	8.38
10	880	0	880	175.00	100.00	440.00	166.00	95.00	12.90
15	920	0	920	201.00	100.00	460.00	169.00	84.00	11.90
20	30	0	930	231.00	100.00	465.00	194.00	84.00	8.95
25	940	0	940	263.00	100.00	470.00	204.00	78.00	7.18
30	60	0	960	272.00	100.00	480.00	211.00	76.00	6.61
35	960	0	960	279.00	100.00	480.00	216.00	77.00	5.88
40	980	0	980	283.00	100.00	480.00	221.00	78.00	5.27
45	1000	0	1000	294.00	100.00	500.00	218.00	74.00	5.17

Table 2 continuation

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
50	1020	20	1000	302.00	98.00	520.00	216.00	72.00	5.04
55	1040	20	1020	305.00	98.00	530.00	216.00	71.00	4.66
60	1060	30	1030	307.00	97.00	545.00	217.00	71.00	4.25
65	1070	40	1030	308.00	96.00	555.00	216.00	70.00	3.62
from lava side									
-10	90	0	90	29.00	100.00	45.00	23.00	70.00	5.60
-5	155	0	155	44.00	100.00	77.50	38.00	86.00	7.10
0	340	0	340	93.00	100.00	170.00	128.00	137.00	4.85
5	590	0	590	182.00	100.00	295.00	153.00	84.00	5.95
10	810	10	800	274.00	99.00	410.00	203.00	74.00	5.40
15	970	10	960	364.00	99.00	490.00	245.00	67.00	3.98
20	990	10	980	387.00	99.00	500.00	261.00	67.00	3.21
25	1130	11	1119	417.00	99.00	570.00	264.00	63.00	4.09
30	1180	20	1160	468.00	98.00	600.00	277.00	59.00	3.19
35	1190	20	1170	488.00	98.00	605.00	276.00	57.00	2.73
40	1190	20	1170	491.00	98.00	605.00	289.00	56.00	2.51
45	1210	30	1180	500.00	97.00	620.00	267.00	53.00	2.46
50	1230	40	1190	514.00	96.00	635.00	285.00	51.00	2.28
55	1230	40	1190	517.00	97.00	635.00	264.00	51.00	1.99
60	1250	60	1190	520.00	95.00	655.00	262.00	50.00	1.99
65	1280	70	1210	524.00	94.00	675.00	261.00	49.00	1.83
offset of the upper point									
-10	320	0	320	106.00	100.00	160.00	82.50	59.00	6.69
5	320	20	300	124.00	94.00	170.00	87.10	54.00	5.53
0	430	20	410	151.00	95.00	225.00	76.90	51.00	7.78
5	440	40	400	191.00	91.00	240.00	84.80	44.00	4.67
10	460	60	400	239.00	87.00	280.00	91.00	38.00	1.86
15	470	80	410	279.00	87.00	265.00	95.00	34.00	1.14
20	590	110	480	311.00	81.00	350.00	106.00	34.00	2.73
25	660	120	540	339.00	82.00	390.00	122.00	36.00	2.96
30	670	120	550	371.00	82.00	395.00	127.00	34.00	1.27
35	870	130	540	400.00	81.00	400.00	134.00	34.00	0.00
40	670	130	540	415.00	81.00	400.00	133.00	34.00	0.87
45	680	140	540	417.00	79.00	410.00	129.00	32.00	0.29
50	690	150	540	420.00	78.00	420.00	128.00	31.00	0.00
55	710	190	520	425.00	73.00	445.00	127.00	30.00	0.88
60	720	210	510	427.00	71.00	465.00	128.00	29.00	1.15
65	730	240	400	429.00	67.00	485.00	128.00	29.00	1.38

Analysis of the results of statistical processing of instrumental mine observations

One of the parameters for estimating the influence of the reference pressure on the fixing of the excavations is the average value of the displacements of the support contour and the support elements relative to each other.

Two sites were measured at the Progress mine. The first was taken on departure from the split furnace and the second one at the steady step of collapse.

On the first site from the side of the massif Umax increase more than 2.5 times (275 ... .730 mm) in the section - 10 ... .70 m. Umax increases by 2.1 times (249 ... ..532 mm) on the worked-out space side. On the side of the roof, Umax increases by 1.4 times (335 ... ..468 mm).

The values of Umin on the side of the massif increase 15 times (10 ... .150 mm) in the section - 5 ... .70 m, on the side of the worked-out space Ucp increases 15.7 times (7 ... .110 mm) in the section 0 ... .70 m, from the side of the roof Ucp increase in 7.69 times (26 ... .200 mm), in section 5 ... ..70 m.

In the second section with a steady regime of the collapse of the roof rocks, the values of Umax from the massif increase 7.6 times (140 ... .1070 mm) in the section - 10 ... .65 m, on the side of the, worked out space Umax increase by 14.2 times (90 ... .1280 mm) from the side of the roof Umax increases by 2.3 times (32 ... ..730 mm).

The values of Umin on the side of the massif increase twofold (20 ... ..40 mm) in the section of 50 ... .65 m, from the side of the, worked out space. Umin increase by 7 times, (10 ... .70 mm) in section 10 ... .65 m, from the side of the roof Umin increase by 12 times (20 ... .240 mm) in the section - 5 ... .65 m.

In the experimental sections taken in the preparatory work carried out under the pillar development system in the conditions of the reservoir h_8 of the Progress mine, protected according to the scheme "massif - sheep - rubble strip", the values of Ucp differ in magnitude in two measurement areas with different distances from the split furnace. In the experimental section, taken as a departure from the split furnace, the value of Ucp increases: from the side of the roof of the massif from 79 mm to 299 mm; From the side of the lava from 65 mm to 344 mm; from the side of the roof from 118 mm to 343 mm.

In the experimental section with steady collapse mode, the values of Ucp exceed the values taken in the section taken away from the split furnace: on the side of the Ucp massif grow from 38 mm to 308 mm, on the side of the worked out space from 29 mm to 524 mm, from the roof side from 106 mm to 429 mm.

The way to protect the mine "Progress", which was covered in the reservoir h_8, is not rational. The displacement value exceeds the permissible level of compliance of the support in 1,2 ... .2,5 times. At the site, when leaving the split furnace in equal mountain-geological and mining conditions at the Progress mine, the layer h8, the Ucp value is less than on the site with the established collapse mode, which indicates the positive effect of the deflecting rock layers on the condition of the work support.

Determining the size of the zone of influence of the dynamic component behind the breakage face

In the zones of influence of clearing faces in the preparatory workings as a result of the change in the strained-deformed state (SDS) of the rocks as a result of the periodic process of hanging and collapse of layers of the roof rocks in the worked-out space, areas with increased and reduced stress and, as a consequence, various displacements of the output contour. This change in the shifts in mine observations is usually considered as a series of distribution of the probable displacements around the mean value. It is also considered to consider the distribution of the probable displacements in the zone of influence of the face face obeying the normal distribution law, therefore the selective characteristics and parameters inherent in this distribution can be used to estimate variability of displacements. One of the main parameters for samples with normal distribution is the average sample value.

In [14], an analysis of Ucp was carried out using the relation:

$$\frac{U_{max} - U_{cp}}{U_{cp} - U_{min}}$$

The values obtained exceeded 1.0, which was explained by the increased stress from the effect of the reference rock pressure, the discrepancies were revealed for all areas ahead of the face, which indicated the deviation of the variation series from the law of the normal distribution of the random displacement value.

With the purpose of revealing the fact of the deviations of the average values of particular samples of the random displacement value from the average population, we tested the null hypothesis about the absence of differences between the parameters of the general population distributed according to the normal law and the parameters of random samples at different distances from the breakage face.

The check was carried out using the *t*-statistics applied when the value of the standard deviation (σ) for the general population is unknown. The value of *t* is determined by the formula:

$$t = \frac{\text{M - Ucp}}{\sigma} \times \sqrt{n}$$

where: Ucp - mean random sample; M - mean population; σ - standard deviation of a random sample; *n* - sample size.

The value of M is determined by the condition that the population belongs to the population with the normal distribution law of the random variable.

$$M = \frac{U_{\max} \text{ - Umin}}{2}$$

The obtained values of *t* are compared with *t*` tabular at a given level of significance. If $t > t`$, then the difference is significant, i.e. There is a deviation from the normal distribution law for a random displacement value.

In the tables of statistical results, the calculated *t* -criterion is indicated, and the dependence of the value of the *t* -criterion on the distance to the bottom hole is plotted.

Analyzing the obtained data on mine observations, it is possible to note significant differences between *t* and *t* in front of the face face and on the side of the massif.

Analysis of the results of the Progress mine in the conditions of the h_8 formation shows a regular decrease in the value of t with the removal from the breakage face.

In the section taken at departure from the split furnace (fig. 3) the largest values of *t* are noted ahead of the face face, on the side of the array, the values of *t* grow from a distance of 10 m ahead of the face face to a value of 12.1 in 5 m before the cleaning face, then the value of *t* decreases.

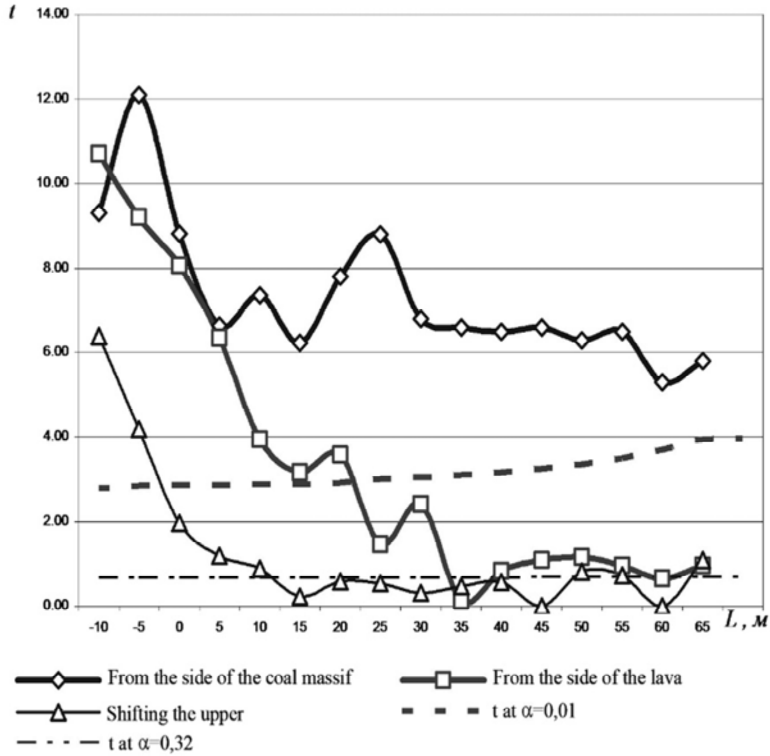

Fig. 3.

However, its value exceeds the values of t`, in the entire measurement area; from the side of the worked out space, the decrease in the value of t is noticeable ahead of the face face and at 25 ... 30 m behind it *t* becomes less than *t* at $\alpha = 0.32$; from the side of the roof, the same character of the decrease of the values of t is noticeable. However, the inequality $t > t`$ is true up to 0 ... .5 m behind the lava.

On a site with a steady collapse mode (fig. 4.) sections with values $t > t`$ are more prolonged than in the section when leaving the cutting furnace.

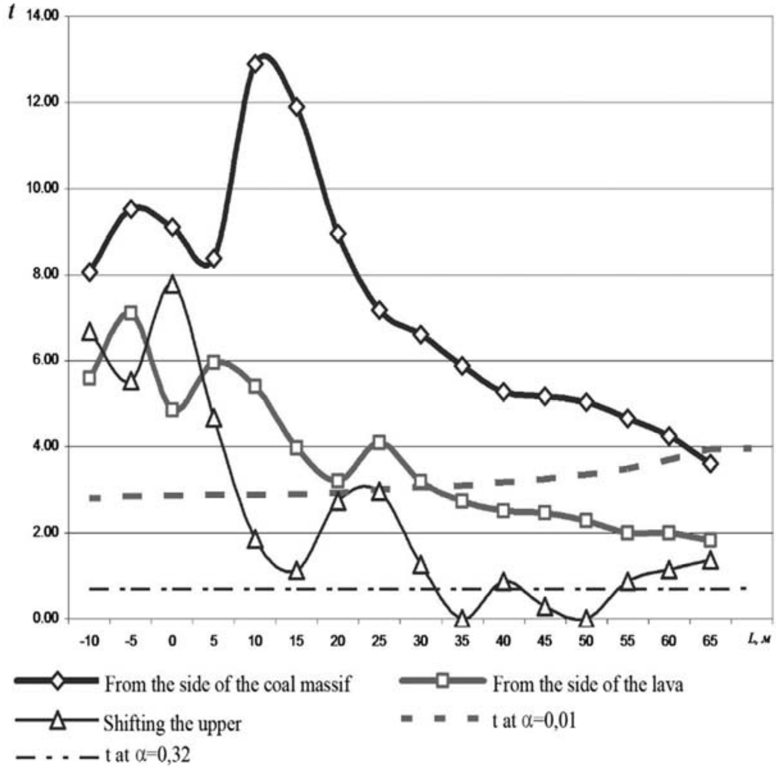

Fig. 4.

The nature of the change in *t* is similar to the changes in the first section; From the side of the array, the increase in t is visible in front of the face face, and go up to 15 m behind it, further decrease, but the inequality $t > t`$ is preserved throughout the measurement area; On the side of the worked out space, the decrease in *t* values goes from 5 m ahead of the face face and becomes less than $t`$ at $\alpha = 0.32$ at 65 m behind it; from the side of the roof of decreasing *t* begins with conjugation and in 15 ... .30 m of the value $t > t`$ at $\alpha = 0,32$ to the end of the site.

When performing the correlation analysis of numerical series of values of the t -test, it shows a significant homogeneity. The coefficient of pair correlation between the values of t criterion: from the side of the array and from the side of the lava in the first experimental section is 0.76; the sides of the lava and the displacements of the "top point" is 0.85; On the side of the array and the shifts of the "top point" is 0.72. The coefficient of pair correlation between the values of the criterion: from the side of the array and from the side of the lava in the second experimental section is 0.75; the sides of the lava and the displacements of the "top point " are 0.77; from the side of the array and the shifts of the "top point" is 0.43, and under the condition of displacement of the reference point of the rows ± 10 m, it reaches 0.84.

In our opinion, the pronounced wave character of the change in the t -criterion over the length of the measuring areas predetermines the places of stress concentration caused by the dynamic component of the rock pressure.

Thus, the deviations of the mean values of the partial samples are greatest in front of the face face and on the side of the massif. The physical meaning of this deviation (divergence) is associated with the influence of cantileverly hanging layers of roof rocks. In addition, the periodic character of changes in the t -criterion is evident, which indicates a non-homogeneous robot of the support for the preparation under the action of the dynamic component of the reference pressure.

Reduction of the dispersion is associated with the action of regular processes, this decrease in this case, in this case, the values of (σ) and as a consequence of the variation (V), are associated with the ordering of the displacements under the action of the regular value of the rock pressure, increasing to γH.

Summarizing the above, it should be noted that the deviations of the mean values of particular samples from the average population value for a random displacement value are caused by the action of the hanging consoles of rock layers, and the increase in the magnitude of the deviations is associated with the formation, growth of consoles, and a decrease in the action of the residual consoles. The effect of the static component associated with the deflection of the overlying layers of rocks is determined by the presence of a normal distribution law for a random displacement value and small deviations from normality. The decrease indicates the effect of the regular value of the rock pressure, which is close in value to geostatic (γH).

Engineering methods of calculating the displacements based on the results of mine instrumental observations use for preparatory workings that are subject to the influence of current clearing works. The method for determining the displacements was approved by [15]. The essence of the technique is that for typical conditions, average rock offsets are determined beyond the term of the impact of the cleaning works, and then the influence of the slope angle, cross-sectional dimensions of the development, the influence of the neighboring excavations, etc., is taken into account with the help of the coefficients. To determine the displacements in affected by the face zones, coefficients are introduced that take into account the thickness of the formation, the influence of the stripe bands, etc. The working time of the development is taken into account by introducing the average displacement velocity and the service life of the production in each reference pressure zone.

This technique also indicates the displacement of the roof rocks in the preparatory workings is the main indicator by which both the support itself and the parameters (compliance and density of the frame installation) are selected. The average descent is the main characteristic of these particular conditions. Assume that equal to the average value offset will be realized along the entire production length and the support parameters chosen on this basis will correspond to these offsets.

In work [15] it is indicated that the displacement of the roof rocks in the preparatory workings is the main indicator by which both the support itself and the parameters (compliance and density of the frame installation) are selected. The average descent is the main characteristic of these particular conditions. It is assumed that an offset equal to the average value will be realized along the entire length of the production and the parameters of the support established on this basis will correspond to these displacements.

However, we have established deviations in the variation series of the random displacement value near the bottom hole, where the average displacement value does not fully reflect the parameters of the displacement process and can not be a universal value of the estimate for determining the fastening and production parameters.

The analysis shows that with the approach to the breakage face, the average value of the partial samples deviates significantly from the average population. Based on t -statistics, the significance of these discrepancies was assessed. The value of t determines for the normal distribution law the number of root-mean-square deviations, which must be left to the right or left of the center of dispersion in order that the probability of entry into the obtained region is $S = 1 - \alpha$. In this case, the significance level was chosen from the considerations that $3{,}2\sigma$ ($3{,}2t$) for the normal distribution law provide $S = 99.99\%$ probability. Thus, at $\alpha \leq 0{,}01$, we can speak of the termination of the dynamic component, and with $\alpha \leq 0{,}32$, the decrease in the action of the most significant layer. The intersection points of the change graph t with the graph of change $t`$ at a given significance level and determine the boundaries of the dynamic component of the reference pressure behind the breakage face.

Recommendations for increasing the sustainability of precinct development workings

The rationale for choosing ways to improve the stability of preparatory excavations is based on the analysis of studies of the manifestations of rock pressure along the length of the preparatory work, the establishment of a clear geomechanical picture, the interaction of rock layers, depending on the distance to the bottom face and the values of the expected displacements. The conducted mine instrumental observations and their analysis make it possible to determine both the places of the most intensive manifestations of the reference rock pressure and to determine the nature of these manifestations.

The generalizing geomechanical picture is as follows. Ahead of the breakage face, the preparatory development experiences increased rock pressure associated with the action of the rock layers and the overlying strata. The length of this zone according to previously conducted observations reaches 250 meters. When approaching the cleaning face, the role of the consoles in the shifts of the workout contour becomes decisive, and their effect is periodic in nature, which is associated with the periodic hanging and collapse of the consoles of rock layers. At the interface of the lava with the preparatory development, their role is especially high because The coal layer, which receives the main load from the overhanging roof rocks, is worked out. Behind the cleaning face at a certain distance, in the zone of reduced influence of the dynamic component of the reference pressure, the work bench experiences loads connected with the action of the residual cantilevers and the weights of the destroyed rocks, this distance determines the zone of action of the dynamic component. With the removal from the lava, further loads are due to the influence of the caving of the overlying layers - the rear "fifth" arch of collapse. Their action regulates the influence of the residual consoles and compacts the collapsed rock of the roof.

The foregoing representations of the geomechanical processes of the length of the preparatory development as a result of the movement of the bottom face predetermine the choice of ways to increase the stability of the mine.

As is known, the choice of ways to protect and maintain preparatory workings is realized by adopting spatial planning solutions and determining, based on the values of expected displacements, technical solutions. In this case, the adoption of spatially planned decisions is due to the nature of the manifestations of the reference pressure, depending on the location of the production relative to the breakage face. Conducted with the lead of the working face of the mine workings fall into the zone of the greatest influence of the dynamic component of the reference pressure, as a result of its periodic impact, the production receives the largest part of the displacements. For the workings carried out behind the cleaning face, the influence of the hanging consoles is not so significant and is due to the size of this zone behind the breakage face. Thus, carrying out excavations with clearance behind the breakage face is more favorable, from the point of view of retaining the workings for reuse, than carrying out excavations ahead of the cut breakage face.

As a basis for making technical decisions to improve the condition of the preparatory workings, a no-pointed technology for working out a coal seam was chosen. Taking into account the existing methods of protection and maintenance of excavations, it is proposed:

when carrying out excavations in a coal massif or ahead of a work face with their subsequent maintenance at the border with the developed space for reuse;

when working off the adjacent column, as well as during the execution (processing) of workings behind the breakage face, with periodic maintenance of measures to reduce its negative influence along the length of the pit in the worked space, in the places of influence of the dynamic component of the reference pressure.

Conclusions

The periodicity of the dynamic component in the choice of methods and means of protection is not currently taken into account. One way to eliminate the increased stress concentrations in the rock mass near the preparatory mine is the active influence on the dynamics and, in part, on the static pressure support. The methods of advanced hydro-micro-torpedoing and explosion-hydro-processing, used to collapse roofing rocks over the breakage face, as a means of controlling the rock mass in the pit column, will positively influence the stability of the preparatory workings. To control the dynamic component of the reference pressure, it is advisable to use shut-off wells laid in the roof of the mine. Taking into account the periodic nature of the formation and hanging of the cantilevers of the rock layers, the use of softening of the backwoods should be carried out in certain areas as the pit is worked. This method is more rational to apply in the workings of the face-off with advanced lead as the work on softening the rock massif in this case can be carried out independently of the works connected with the performance and protection of the mine.

The second way to increase the stability of preparatory excavations may be the method of creating artificial supports in the worked out space to reduce the increased stresses caused by the periodic formation and collapse of the consoles of the rock layers of the roof. The decrease in the influence of the reference rock pressure can be achieved by periodically amplifying the dynamic component of the reference pressure at the points of influence. This method can be used rationally in carrying out preparatory workings behind the breakage face, since the concentration of mining operations in the zone adjacent to the preparatory face is extremely high.

Thus, for the protection of preparatory excavations with an aimless technology for working out a coal seam in order to reduce the displacement of the roof rocks in preparatory workings for the conditions of medium-stable and stable rocks of the immediate roof and middle-collapsing rocks of the main roof, weaken the most significant layers of the roof by blasting explosive in shut-in wells. The shut-off wells should be located ahead of the breakage face and the distance between them is taken to be equal to half the step of collapse of the most significant layer, as with further increase in the stress-breaking step in the clamp of the console (ahead of the breakage face and the massif of the mine), it increases significantly. For these conditions, this distance is 15 ... .20 meters. An additional means of protection is a cast strip of fast-hardening materials, erected in the worked-out space after the cleaning face. At the interface of the mine with the breakage face, a reinforcing support must be installed.

The given recommendations are proposed for working out of a direct roof and medium-collapsed rocks of the main roof, preserved for the purpose of repeated use in conditions of medium-stable and stable rocks, at depths

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The conducted studies show that along the length of the preparatory workings in the zone of influence of the cleaning works, the values of the rock displacements on the contour have a wide spread due to the periodic nature of the manifestations of the reference pressure. Displacements of the contour of the preparation workings often exceed the compliance of the three- and five-tier compliant arched supports. The major part of these displacements occurs in the zone of dynamic manifestations of the reference pressure. The static component of the reference pressure accounts for up to 70% of all displacements in the reference pressure zones.

In this regard, it is important to know what the role of different layers in the formation of reference pressure. An important task is also to establish the parameters of the reference pressure, taking into account the equity participation in the process of displacement of the dynamic and static components.

The refinement of the geomechanical picture of the behavior of the roof rocks, using statistical indicators, will allow more justified choice of ways to protect and maintain workings stored for reuse.

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STRESS-DEFORMED STATE OF SOIL AT THE EXPLOSION OF CYLINDRICAL CHARGE OF NEW INDUSTRIAL MIXED EXPLOSIVES

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Abstract

Within the limits of zone model in solid rocks, the problem of development in time of destruction zones while cylindrical charge explosions is solved. At that the energy approach in dynamic description of the grinding zone is used. For a zone of radial cracks, a quasi-static description while determining stresses and deformations is used. Behavior of detonation products is described by a binomial isentropic equation of state. Algorithm is developed and implemented, program for PC for a numerical solution of problem is compiled. Subject of the study is new industrial blended explosives. Purpose of the study is to determine the impact of characteristics of new industrial blended explosives and physical and mechanical properties of rocks on parameters of destruction zones. It is established that with increase of similarity criterion $x = D^2/A_i$ (D – detonation velocity, A_i – complete ideal work of explosion), the relative magnitudes of radii of camouflage cavities, zones of grinding and radial cracks for each of investigated solid rocks are increased. It is established that values of parameters of destructive zones in solid rock at the explosions of cylindrical charges of new blended explosives are greater than values of parameters of destruction zones in blowings up of standart explosives, therefore, new explosives can be effectively used for crushing solid rocks in quarries.

Introduction

At the present stage of development of soil and rock mechanics, special attention is paid to problems of their deformation by explosion charges of industrial chemical explosives. However, for subversive works, there is still a small coefficient use of explosion energy, an increase in requirements of technological and environmental safety, economic inappropriateness of use of expensive explosives from plants. Therefore, several dozen of new industrial non-trotyl explosives are developed. Practical application of these explosives has satisfactory results regarding area of rocks destruction by bursts of borehole charges. At the same time, conclusions about effectiveness of new explosives don’t have a theoretical basis, and are based on visual observation of experimental and practical results of explosions mainly [1, 6].

It is obvious that full characteristics of these explosives can be obtained only considering results of specially executed scientific studies of interaction of system "explosive substance - products of explosion - rock". Such results can be obtained not with the help of empiro-analytical calculations, which are present in most recent scientific publications in this direction, but only on the basis of numerical studies of mathematical models of dynamics of this system in general statements, since only in this case one can take into account connectivity, that is mutual conditionality of parameters of different stages of development of explosion in rocks.

Therefore, mathematical modeling of process of destruction of rock by cylindrical charges of new blended explosives for substantiation of effectiveness of their application is *actual scientific and practical task*.

Aim of the study is to determine impact of characteristics of explosives and physical and mechanical properties of rocks on parameters of destruction zones.

Mathematical formulation of problem

Deformation and destruction of a brittle medium under influence of explosion of a cylindrical charge of an explosive of infinite length and radius a_0 is considered. It is assumed that charge detonates instantaneously and the same average pressure P_{cp} throughout its whole volume is set, and density of detonation products is equal to initial density of explosive.

Impact of new explosives on destruction zones

Expansion of detonation products takes place in accordance with the binomial isentropy:

$$P(a) = A\rho^{n_0} + B\rho^{\gamma_0+1}, \qquad (1)$$

where a – the current radius of cavity of explosion.

The constants A, B, n_0, γ_0 in (1) are calculated uniquely according to known detonation characteristics of explosives.

To study effect of explosion in rock a known zone model of V.M. Rodionov, modified by Y.M. Sher in case of fragile rocks, is used.

Let the deformation of medium be flat, wave processes are not taken into account. In this case, shock wave removes rapidly from cavity of explosion, fields of stress and deformation are close to static and are determined for loading at a fixed time point. In the development of explosion, the following stages are distinguished [7 - 11].

In the first stage, wave of destruction extends at a rate which is greater than the maximum speed of motion of cracks υ_{max}. At this stage, there are two zones: plastic at $a \le r \le b$ and elastic at $r(t) > b(t)$ ($a(t)$ – the radius of cavity of explosion, $b(t)$ – the boundary of plastic zone, $r(t)$ – the current coordinate).

At the second stage of destruction, with decreasing the growth rate of plastic zone and the performing of inequality $b \le \upsilon_{max}$, a zone of radial cracks appears at $b(t) \le r \le l(t)$, where $l(t)$ – the radius of radial cracking fronts. At a distance $r > l(t)$ there is a zone of elastic deformation [10].

In the model, it is assumed that in zone of radial cracks for stresses and strain, static correlations for loads at the current moment are performed. From analysis of results of experimental studies, it is known that at the development of zone of radial cracks there is a decrease in their number. Part of cracks stops, and as a result others develop further.

Near charge in grinding zone, the equations of saving of amount of motion and saving of mass of continuous friable medium are performed. For the one-dimensional case at the explosion in cylindrical coordinates (r,θ) they have the form:

$$\rho\left(\frac{\partial\upsilon}{\partial t}+\upsilon\frac{\partial\upsilon}{\partial r}\right)=\frac{\partial\sigma_r}{\partial r}+\frac{\sigma_r-\sigma_\theta}{r},$$

$$\frac{\partial\rho}{\partial t}+\upsilon\frac{\partial\rho}{\partial r}+\rho\frac{\partial\upsilon}{\partial r}+\frac{\rho\upsilon}{r}=0, \tag{2}$$

where ρ – the density of medium; υ – the radial velocity; t – time; σ_r, σ_θ – the radial and tangential components of stress tensor.

Behavior of friable medium is described by the Mohr-Coulomb law [8]:

$$\tau = C - \sigma\cdot tg\varphi, \tag{3}$$

where τ, σ - the tangential and normal tension in landslide area.

In principal stresses of an axisymmetric problem, when expanding the cavity of explosion in this zone, the condition of fluidity can be written as

$$(1+\alpha)\sigma_\theta-\sigma_r-Y=0\,,\; Y=2C\cos\varphi/(1-\sin\varphi)\,,$$

$$\alpha=2\sin\varphi/(1-\sin\varphi)\,, \tag{4}$$

where Y and α - the resistance of motion and the coefficient of medium friction, respectively.

Relation (4) is executed if displacement sites are parallel to axis of symmetry. This is executed when the initial pressure compression with rock pressure along the Z axis is average in relation to compression along other axes.

Considering the rock as non-shear at front of wave in grinding zone, after integrating the second equation (2) we obtain an expression for the velocity of rock particles

$$\upsilon(r,t)=a\dot{a}/r\;. \tag{4}$$

Defining $d\upsilon/dt$, $d\upsilon/dr$ from (5) and excluding σ_θ from (2) with (4), we obtain the equation for σ_r:

$$\frac{\partial\sigma_r}{\partial r}+\frac{\alpha}{(1+\alpha)}\frac{\sigma_r}{r}=\frac{Y}{(1+\alpha)r}+\rho\left(\frac{\ddot{a}a+\dot{a}^2}{r}-\frac{(\dot{a}a)^2}{r^3}\right). \tag{5}$$

The general solution of this equation:

$$\frac{\partial\sigma_r}{\partial r}+\frac{\alpha}{(1+\alpha)}\frac{\sigma_r}{r}=\frac{Y}{(1+\alpha)r}+\rho\left(\frac{\ddot{a}a+\dot{a}^2}{r}-\frac{(\dot{a}a)^2}{r^3}\right). \quad (6)$$

where *F(t)* - the time function to be determined.

For displacement u_b at boundary of grinding zone $r=b(t)$ from the condition of incompetence of medium it follows:

$$a^2-a_0^2=b^2-(b-u_b)^2, \quad (7)$$

where a_0 - the charge radius.

In zone of radial cracks at $b(t)\le r\le l(t)$:

$$\sigma_\theta=0,\ \ \sigma_r=-p_b b/r,$$

$$\frac{du}{dr}=-(1-\nu^2)p_b b/(Er), \quad (8)$$

$$u=u_0(t)-(1-\nu^2)(p_b/E)b\text{In}(r/a_0),$$

where p_b – the radial pressure at $r = b$; u – the radial displacement; E, ν – the Jung's and Poisson's modules of destroyed medium; $u_0(t)$ - the arbitrary time function.

In zone of elasticity for a case of flat deformation a general solution at $r>l(t)$

$$\sigma_r=-p-EB/\left[(1+\nu)r^2\right],\quad \sigma_0=-p+EB/\left[(1+\nu)r^2\right],$$

$$u=B/r-(1+\nu)(1-2\nu)rp/E. \quad (9)$$

where p – the current pressure, B – the arbitrary constant.

The arbitrary functions *F(t)*, $u_0(t)$, *B(t)* in formulas (6), (8), (9) are determined from the initial and limit conditions of the problem.

For the first stage of explosion, the following limit conditions are fulfilled. At the edge of the "cavity of explosion - a breed", the radial stress in grinding zone is equal to pressure of gases in cavity

$$\sigma r = -P(a) \quad \text{at} \quad r = a(t) \quad (10)$$

Before wave of crushing in an elastic medium, the criterion of shear destruction of medium is fulfilled

$$(1+\alpha_2)\sigma_\theta-\sigma_r-Y_2=0 \quad \text{at} \quad r=b(t). \quad (11)$$

Radial offsets are continuous left and right of boundary of plastic zone b, i.e.

$$u(b-0)=u(b+0)=u_b. \qquad (12)$$

The criterion of destruction (11) corresponds to a straight-forward enveloping circle of Mor [8]. Parameters Y_2 and α_2 are determined by results of uniaxial tests in tensile σ_c and compression σ_p:

$$\alpha_2=\sigma_c/\sigma_p-1, \quad Y_2=\sigma_c. \qquad (13)$$

In a quasi-static approach, stresses are assumed to be continuous at the transition through a crushing wave. At this, kinetic energy of medium in grinding zone increases with increasing b due to addition of moving layers of elastic zone, which has no kinetic energy formally. The emerging paradox is associated with neglect of inertial terms in description of elastic zone. As an amendment to quasi-static description, it is proposed that in crushing wave there is an overclocking of particles of medium from zero velocity to u_b. This leads to stress value in grinding area at $r=b(t)-0$ in:

$$\sigma_r(b-0)=-\rho u_b\dot{b}+\sigma_r(b+0), \qquad (14)$$

where ρ - the density of medium in crushing zone.

From conditions (7), (11), (12) for values $(a^2-a_0^2)/b^2 \ll 1$:

$$\frac{b}{a}=n\sqrt{1-\frac{a_0^2}{a^2}}, \quad n=\sqrt{\frac{E(2+\alpha_2)}{2(1+\nu)(Y_2+p\alpha_2)}}, \quad \frac{u_b}{b}=\frac{1}{2n^2}. \qquad (15)$$

As $\sigma_r+\sigma_\theta=-2P$, from conditions (11):

$$\sigma_r(b+0)=-\left[Y_2+2p(1+\alpha_2)\right]/(2+\alpha_2).$$

It follows from (13), (15):

$$\sigma_r(b-0)=\sigma_r(b+0)-\rho a^2\dot{a}^2/\left[2\left(a^2-a_0^2\right)\right]. \qquad (16)$$

Let introduce dimensionless variables: the scale of length – a_0, of time – a_0/c_0 ($c_0=\sqrt{E/\rho}$ – the local velocity of sound), of stresses – E. Substituting the general solution (6) into the boundary conditions (10) and (16) and using (15), we obtain for the radius of cavity $a(t)$ in dimensionless form the camouflage equation:

$$K_1(a)a\ddot{a} + (K_1(a) - K_2(a))\dot{a}^2 + K_3 - P(a) = 0,$$

$$\text{where } K_1(a) = ((1+\alpha)/\alpha)\left[m^{\alpha/(1+\alpha)} - 1\right],$$

$$K_2(a) = ((1+\alpha)/(2+\alpha))\left[1 - m^{-(2+\alpha)/(1+\alpha)}\right] - (a^2/2(a^2-1))m^{\alpha/(1+\alpha)}, \quad (17)$$

$$K_3(a) = ((Y_2 + 2(1+\alpha_2)p/(2+\alpha_2) + Y/\alpha)m^{\alpha/(1+\alpha)} - Y/\alpha,$$

$$m = n\sqrt{1 - 1/a^2} = b/a.$$

At the second stage of explosion there are three zones with such boundary conditions. On cavity of explosion $\sigma_r = -P(a)$ at $r = a(t)$ on the border of crushing zone

$$u(b-0) = u(b+0), \quad \sigma_r(b-0) = \sigma_r(b+0) - \sigma_1, \quad \sigma_1 \le \sigma_c \quad (18)$$

at $r = b(t)$, at the front of radial cracks

$$u(l-0) = u(l+0), \quad \sigma_r(l-0) = \sigma_r(l+0) = q \quad \text{at} \quad r = l(t).$$

When the equality for stresses (18) performed, the crushing in rod-shaped zone of radial cracks occurs, and *b(t)* increases with time. In the opposite case, the boundary of grinding area is stationary at $\sigma_r(b+0) > -\sigma_c$ and $b = 0$.

Using (8) – (10) and excluding $u_0(t)$ from (18), in approximation in $(a^2-1)/b^2 \ll 1$:

$$u_b \approx \left(a^2 - 1\right)/\left(2b\right), \quad (19)$$

$$\left(a^2-1\right)/\left(2b^2\right) + \left(1+\nu\right)\left(pl/b - \sigma_1\right) + \left(1-\nu^2\right)\sigma_1 \ln\left(b/l\right) -$$
$$-\left(1+\nu\right)\left(1-2\nu\right)p\left(1 - l/b\right) = 0$$

From the second relation (19) at $\sigma_1 = \sigma_c$, with differentiation of *t:*

$$\dot{b} = \frac{\dot{l}\left(\left(1-\nu^2\right)\sigma_c\left(b/l\right) - 2\left(1-\nu^2\right)p\right) - \dot{a}\left(a/b\right)}{\left(1-\nu^2\right)\sigma_c - \left(a^2-1\right)/b^2 - 2\left(1-\nu^2\right)p\left(l/b\right)}, \quad (20)$$

$$b = 0 \text{ at } \sigma_1 < \sigma_c.$$

Substituting (6) into the boundary conditions on cavity of explosion and the boundary of grinding zone, and excluding *F(t)* we obtain the camouflate equation for the second stage of explosion (destruction):

$$\bar{K}_1(a)a\ddot{a} + (\bar{K}_1(a) - \bar{K}_2(a))\dot{a}^2 + \bar{K}_3(a) - P(a) = 0, \qquad (21)$$

where

$$\bar{K}_1(a) = ((1+\alpha)/\alpha)\left[m^{\alpha/(1+\alpha)} - 1\right],$$

$$\bar{K}_2(a) = ((1+\alpha)/(2+\alpha))\left[1 - m^{-(2+\alpha)/(1+\alpha)}\right],$$

$$\bar{K}_3(a) = ((\sigma_1 + Y/\alpha)(m^{\alpha/(1+\alpha)} - 1) + \sigma_1,$$

at $\sigma_l < \sigma_c$ from the second relation (19) it follows:

$$\sigma_1 = \frac{\left(a^2-1\right)/\left(2b^2\right) + \left(1+\nu\right)p\left(2\left(1-\nu\right)l/b - 1 + 2\nu\right)}{\left(1+\nu\right) + \left(1-\nu^2\right)\ln\left(l/b\right)}.$$

For the radius of radial cracks *l(t)* in dimensionless form [12, 13]:

$$\dot{l} = \begin{cases} 0, \gamma < \gamma_0, \\ \dfrac{\upsilon_{\max}}{c_0} \dfrac{1 - \exp\left(-\beta(\sqrt{\gamma/\gamma_0} - 1)\right)}{1 - \exp\left(-\beta\left(\sqrt{\gamma_1/\gamma_0} - 1\right)\right)}, \gamma_0 < \gamma < \gamma_1, \\ \upsilon_{\max}/c_0, \gamma \geq \gamma_1, \end{cases} \qquad (22)$$

where γ_0, γ_1 – the specific superficial energy of cracking at moving from place to place and branching start.

Dependence (22) is proposed in [11, 13] as an interpolation for experimentally determined passport dependencies of a number of fragile rocks, which bind resistance to crack and speed of cracks development. At this, the current value γ is determined in the case of flat deformation and axial symmetry from energy condition at the front of radial cracks [9]:

$$2\gamma = \frac{1-\nu^2}{E}\left(2p+q\right)^2 \frac{\pi l}{N}, \; q = -\sigma_1 \frac{b}{l}, \qquad (23)$$

where $N = 64$ – the initial value of the number of cracks in breed.

Results of numerical calculations. Integration of ordinary differential equations of the second order (17) and (23) is carried out numerically by 4th-order Runge-Kutta method.

Studies are made with such solid rock formations: limestone, ferruginous quartzite, granitoids. The physical and mechanical characteristics of these rocks are taken from [14] and are shown in Table 1.

By classification [14] the investigated breeds by the nature of destruction belong to the second group.

Values of maximum cracking rate υ_{mp} are determined by formula [15]:

Table 1

Average values of the parameters of state of solid rocks

Parameter \ R	*Limestone*	*Quartzite*	*Granitoids*
Density ρ, kg/m^3	2500	3350	2690
Young's module $E \cdot 10^{-10}$, Пa	3,4	4,1	4,6
Poisson's coefficient ν	0,25	0,16	0,12
Shear modulus, $G \cdot 10^{-10}$, Пa	1,36	1,77	2,05
Compressive strength limit $Y_2 = \sigma_c \cdot 10^{-8}$, Пa	0,5	0,8	0,62
Boundary of tensile strength $\sigma_p \cdot 10^{-7}$, Пa	0,45	0,72	0,57
Boundary of displacement strength $\sigma_t \cdot 10^{-7}$, Pa	2,43	4,0	2,82
Velocity of longitudinal waves $C_0 = \upsilon_p$, m/s	2800	3610	4170
Velocity of transverse waves υ_s, m/s	1700	2300	2800
Coupling $C \cdot 10^{-5}$, Pa	30	98	44
Angle of internal friction φ, grade	42	42	41
Angle of natural slope	40	36	38
Maximum crackling speed υ_{mp}, m/s	1766	2169	2556
Specific surface energy of cracking: a) at shrinking cracks γ_0, J/m^2 b) at beginning of branching γ_1 J/m^2	54,1 216,4	119,3 477,2	63,7 254,8
$Y \cdot 10^{-5}$, Pa	1,475	4,82	2,284
a	4,04	4,04	3,81
a_2	10,11	10,11	9,877

Table 2

Average arithmetic values of parameters of standard and studied explosives

Parameter \ Explosives	Grammonite 79/21 (1)	Ihdanite (2)	Polymix GR4-T10 (3)	Polymix GR1/8 (4)	Polymix GR1/8 (85%)+ KRUK2 (15%) (5)	Polymix GR1/8 (74%)+KRUK2 (26%) (6)	Kompolaite GS6 (7)
Heat of explosion Q, kcal/kg/ kJ/kg	$\frac{1031}{4312,4}$	$\frac{928}{3885,3}$	$\frac{923}{3864,4}$	$\frac{942}{3943,9}$	$\frac{856}{3583,8}$	$\frac{801,5}{3355,7}$	$\frac{936}{3919,7}$
Explosives density, kg/m^3	950	850	872	875	950	1000	852
Density at the Zhuge point, kg/m^3	1375	1240	1270	1273	1364	1425	1245
Detonation speed, m/s	3300	2500	3150	3600	3700	3900	2550
Pressure at the Zhuge point, GPa	3,2	1,68	2,71	3,55	3,94	4,54	1,75
Adiabat indicator, $k_0 = C_P / C_V$	1,248	1,264	1,245	1,245	1,242	1,242	1,235
Polytropic index, k_n	2,233	2,163	2,189	2,194	2,293	2,348	2,158
Temperature of explosion,K	3243	2838	2879	2893	2793	2717	2861
Parameters of the formula $P = A\rho^{n_0} + B\rho^{\gamma_0+1}$							
A	2,7769	$1,112 \cdot 10^{-5}$	5,67	56,682	43,96	59,345	7,671
n_0	2,8225	4,4098	2,7327	2,4743	2,482	2,4839	2,241
$B \cdot 10^{-5}$	1,4519	1,502	1,2789	1,015	0,68	0,604	1,638
γ_0	0,248	0,264	0,245	0,245	0,242	0,242	0,235

Note. Sequential numbering of explosives are shown in brackets.

$$\upsilon_{mp} = 0,6\upsilon_s \left[2\left(\frac{1-\nu}{1-2\nu} \right) \right]^{\frac{1}{2}}, \quad (28)$$

where υ_s - the velocity of transverse waves, ν - the Poisson's coefficient.

Value of specific surface energy of cracking at the shifts in cracks γ_0 is determined by the formula obtained with a simple extension in accordance with the Griffiths theory [16]

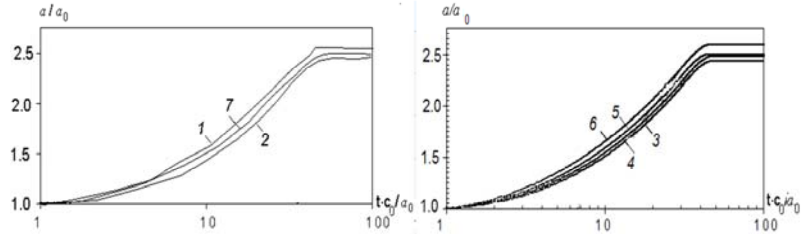
$$\gamma_0 = \frac{\sigma_c^2 \pi \Delta_0 (1-\nu^2)}{2E}, \quad (29)$$

where σ_c – the boundary strength of compression of hard rock, $\Delta_0 = 0,5 \cdot 10^{-3}$, m –half-width cracks, E – the modulus of elasticity of rock. To perform the calculation, the fixed value of the specific surface energy of the cracking is selected at the beginning of branching $\gamma_1 = 4\gamma_0$.

Detonation characteristics of explosives are shown in Table 2, where besides the factory (grammonite 79/21 and ihdanit) are also considered new industrial blends of explosives by local preparation.

In Fig. 1 there are the dependences of relative radius of cavity a / a_0 on relative time at the explosions in limestone of different explosives. The numbering of the curves in the figures is as follows. In Fig. 1, *a*: *1* - gramonite 79/21, *2* - ihdanite, *7* - kompolaite GS 6, in Fig. 1, *b*: *3* - polymyx GR4-T10, *4* - polymyx GR1/8, *5* - polymyx GR1/8 (85%) + KRUK2 (15%), *6* - polymyx GR1/8 (74%) + KRUK2 (26%).

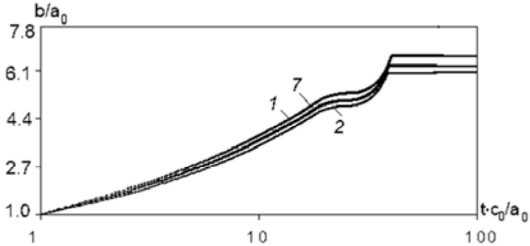
From the analysis of Fig. 1 it follows that the greatest value of relative radius of cavity is achieved at the explosions of charges of polymyx GR1/8 (74%) + KRUK2 (26%), then - polymyx GR1/8 (85%) + KRUK2 (15%), polymyx GR1/8, then grammonite 79/21, polymyx P4-T10, compolaite GS6 and ihdanite. Such a distribution of the maximum values of relative cavity radii is in directly dependence from the initial pressure and density of detonation products, namely: the more pressure and density of detonation products, so the greater value of radius of camouflage cavity.



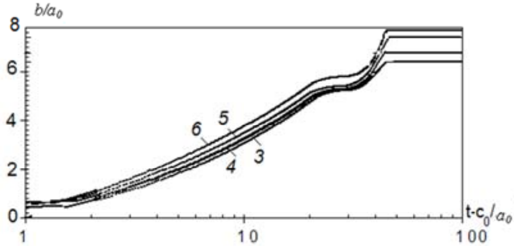
a) ***b)***

Fig. 1. Dependence of relative radius of the camouflage cavity on the relative time at the explosions in the limestone of different explosives

In Fig. 2 *a, b* there are the dependences of relative radius of grinding zone b / a_0 on relative time. From Fig. 2 it is seen that the distribution of the maximum values of grinding zones depending on the different explosives is the same as for the radii of the camouflage cavity. The only difference is that at the explosions of polymyx GR4-T10 and grammonite



a)



b)

Fig. 2. Dependence of relative radius of crushing zone on relative time at the explosions in limestone of cylindrical charges of different explosives

79/21, the close relative values of relative grinding zones b / a_0 are achieved.

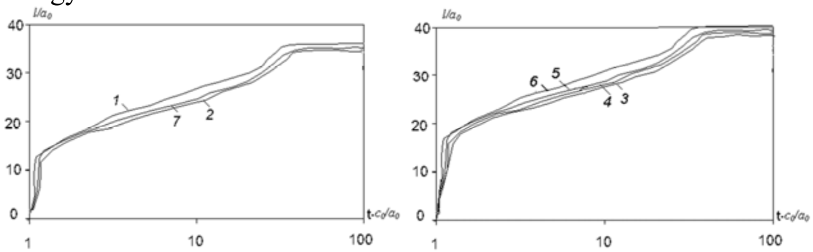
In Table 3 the final values of the parameters of destruction zones at the explosions of cylindrical charges of new blended explosives in limestone are shown. The values of pressure in DP for moments of time of stopping of camouflage cavity development, zones of grinding and radial cracks are also shown. From the analysis of Table 3 it follows that the higher values of the studied parameters are achieved at lower values of pressure in cavity of explosion. This indicates a more complete transfer of energy from explosion of breed, that is, the greater effectiveness of explosives.

Table 3

The final values of the parameters of destruction zones in bursts of cylindrical charges of different explosives in limestone

Parameters / Explosives	a/a_0	Pressure in DP at stop of cavity $P \cdot 10^{-6}$, Pa	b/a_0	Pressure in DP at stop of b/a_0 $P \cdot 10^{-5}$, Pa	l/a_0	Pressure in DP at stop of l/a_0 $P \cdot 10^{-5}$, Pa
Grammonite 79/21	2,55	5,8	7,26	8,1	36,7	4,4
Ihdanite	2,51	5,91	7,13	8,31	36,44	4,51
Polymix GR4-10	2,54	4,95	7,26	7,6	36,77	3,93
Polymix GR1/8	2,61	3,1	7,47	6,7	37,55	3,3
Polymix GR1/8(85%) + + KRUK2(15%)	2,67	2,9	7,7	5,6	39,55	2,8
Polymix GR1/8(74%) + + KRUK(26%)	2,81	2,7	7,99	4,9	40,2	2,2
Kompolaite GS 6	2,52	5,88	7,16	8,2	36,48	4,46

In Fig. 3, *a, b* there are the dependences of the relative radii of zones of radial cracks on the relative time at the bursts of the cylindrical charges of different explosives in limestone. From the consideration of drawings, it follows that the distribution of the maximum values of relative radii of radial cracks l / a_0, depending on different explosives, is the same as for the relative radii of cavity and the radii of grinding zones and is in a direct proportional dependence on pressure and density of explosives DP. Only l / a_0 at the explosion of charge of polymyx GR4-T10 are larger than at the explosion of grammonite 79/21 (although this excess is negligible). This can be explained by the fact that the polytropic index of grammonite 79/21 is larger than of polymix GR4-T10, which causes more intense fading of shock waves, that is, greater dissipation of energy.



a) ***b)***

Fig. 3. Dependence of relative radius of zone of radial cracks on relative time at the bursts of cylindrical charges of different explosives in limestone

In studying the laws of the distribution of the maximum values of the investigated parameters in ferruginous quartzites and granitoids, depending on the types of explosives are the same as in limestone. However, the maximum values a/a_0, b/a and l/a_0 in ferruginous quartzites are smaller than in limestone. This is due to the fact that ferruginous quartzite has a higher density and higher strength characteristics - shear modulus, the coefficient of volume compression, the boundary of tensile strength and displacement, coupling. For granitoids, the values of radii of investigated zones are less than for limestone and quartzite. This is due to the fact that strength characteristics of granitoids are much larger than that of limestone.

Compared with quartzite, granitoids have lower density and lower strength characteristics, but granitoids have much lower the specific energy of cracking, which causes an increase in zones of destruction in quartzites.

In Table 5 the final values of parameters of destruction zones at bursts of cylindrical charges of new blended explosives in granitoids are shown.

According to known end values of pressures in cavity at moments of stopping growth *a, b, l* (Table 3–5) in limestones, ferruginous quartzites and granitoids, using the indicators of adiabat, polytropes of expansions of explosive products and the indicator of adiabat at their expansion to atmospheric pressure, similarity criteria χ_i are calculated (i = 1 ... 7) for each of the seven studied explosives. Next, using the least squares method, dependencies of relative parameters $\frac{a}{a_0}, \frac{b}{a_0}, \frac{l}{a_0}$ for the studied breeds on criteria χ are obtained (Tables 3 – 5).

Table 4

The final values of the parameters of destruction zones in bursts of cylindrical charges of different explosives in ferruginous quartzite

Parameters / Explosives	a/a_0	Pressure in DP at stop of cavity $P \cdot 10^{-6}$, Pa	b/a_0	Pressure in DP at stop of b/a_0 $P \cdot 10^{-5}$, Pa	l/a_0	Pressure in DP at stop of l/a_0 $P \cdot 10^{-5}$, Pa
Grammonite 79/21	2,07	5,3	4,43	8,41	30,52	4,91
Ihdanite	1,98	6,31	4,2	8,73	30,41	5,01
Polymix GR4-10	2,06	5,2	4,42	8,01	30,56	4,8
Polymix GR1/8	2,16	3,5	4,69	7,1	31,86	4,6
Polymix GR1/8(85%) + +KRUK2(15%)	2,28	3,31	5,02	6,03	34,87	4,5
Polymix GR1/8(74%) + + KRUK(26%)	2,48	3,03	5,36	5,32	35,01	4,3
Kompolaite GS6	1,99	6,1	4,3	8,62	30,49	4,07

Table 5

Parameters of destruction zones in bursts of cylindrical charges of different explosives in granitoids

Parameters / Explosives	a/a_0	Pressure in DP at stop of cavity $P \cdot 10^{-6}$, Pa	b/a_0	Pressure in DP at stop of b/a_0 $P \cdot 10^{-5}$, Pa	l/a_0	Pressure in DP at stop of l/a_0 $P \cdot 10^{-5}$, Pa
Grammonite 79/21	2,05	5,9	4,8	8,11	43,3	4,81
Ihdanite	1,91	6,2	4,49	8,62	42,44	4,91
Polymix GR4-10	2,04	5,11	4,79	7,92	43,36	4,77
Polymix GR1/8	2,12	3,37	5,14	7,01	45,05	4,14
Polymix R1/8(85%) + KRUK2(15%)	2,24	3,22	5,48	5,94	47,62	3,96
Polymix GR1/8(74%) + + KRUK(26%)	2,39	2,99	5,92	5,19	49,28	3,8
Kompolaite GS 6	1,93	6,1	4,53	8,3	42,6	4,88

These dependencies are expressed by linear ratio

$$\frac{a}{a_0}, \frac{b}{a_0}, \frac{l}{a_0} = \alpha_j \chi + \beta_j, \quad j = 1,2,3. \tag{30}$$

Obtained averaged dependences can be written as:

for limestone

$$\frac{a}{a_0} = 0,0895\chi + 2,2908, \quad \frac{b}{a_0} = 0,268\chi + 6,5551,$$

$$\frac{l}{a_0} = 1,2802\chi + 33,57; \tag{31}$$

for granitoids

$$\frac{a}{a_0} = 0,1497\chi + 1,5703, \quad \frac{b}{a_0} = 0,4533\chi + 3,5423,$$
$$\frac{l}{a_0} = 2,2244\chi + 37,6586; \tag{32}$$

for ferruginous quartzites

$$\frac{a}{a_0} = 0,1410\chi + 1,6481, \quad \frac{b}{a_0} = 0,3682\chi + 3,4195,$$
$$\frac{l}{a_0} = 1,6286\chi + 26,7909. \tag{33}$$

From the analysis of these dependencies, it follows that with the increase of the similarity criterion χ the relative values a / a_0, b / a_0, l / a_0 increase for each of the seven studied explosives.

Dependences of the relative radius of grinding zone of hard rock on criteria χ are in direct accordance with the strength characteristics of the rocks, namely: the less the values $\rho, E, G, \sigma_c, \sigma_P$, so the greater the final values of the relative radius of grinding zone. The smallest value b / a_0 is achieved at the blasts in quartzite, then in granitoids, most of all - in blasts in limestone.

Analyzing dependences of relative radius of the camouflage cavity a / a_0 on the similarity criteria χ, it is evident that the greatest value a / a_0 is observed at the explosions in limestone, which has the smallest values of strength characteristics. But although quartzite has stronger strength characteristics than granitoids, however, quartzite produces larger values a / a_0 than granitoids. This can be explained from energy considerations as follows. Compared with granitoids, quartzite has a much larger specific surface cracking energy at cracking γ_0 and at the beginning of branching γ_1, which creates conditions for more intensive development of the process at the first stage of destruction.

It is established that the smallest relative radius of radial cracks l / a_0 is achieved during explosions in the strongest of studied rocks - ferruginous quartzite, and the largest at the explosions in granitoids. This is due to the fact that even granitoids have higher strength characteristics in comparison with limestone, but the maximum speed of cracks formation in granitoids is also much larger than that of quartzite and limestone, which causes higher values l / a_0.

Finally, the conclusion can be formulated that the laws of changing relative radii of the camouflage cavity, zones of grinding and radial cracks at the explosions of cylindrical charges in various solid rocks depend not only on the strength parameters, but also on the speed and energy characteristics of the cracking process.

Conclusions

Based on the research and the analysis of obtained results, the following conclusions can formulated:

1) within the zone model of the explosion in solid rock, a closed system of equations is developed for describing their destruction caused by blasts of cylindrical charges of different explosives. At this, the energy approach is used in the dynamic description of grinding zone. For a zone of radial cracks, a quasi-static description is used to determine stresses and deformations. The behavior of detonation products is described by a binomial isentropic equation of state;

2) algorithm is developed and implemented, a program for the PC is compiled for a numerical solution of tasks related to the development of explosion zones in fragile hard rock at the explosions of standard and new industrial blended explosives;

3) influence of explosives characteristics on parameters of solid rock destruction zones is investigated. It is established that the maximum values of relative radii of camouflage cavity, zones of grinding and radial cracks for different explosives are in a direct proportional relationship to pressure and density of detonation products. Only the relative radius of radial cracks zone during the explosions of polymyxes GR4-T10 is greater than during the explosion of gramonium 79/21. This can be explained by the fact that

the polytropic index in gramonite 79/21 is greater than in the polymyx GR4-T10, which causes a more intense extinction of explosive waves in gramonite 79/21;

4) influence of physical and mechanical characteristics of various solid rocks on the development of zones of destruction is investigated. It is found that the largest values of the finite radii of destruction zones at the explosions of cylindrical charges of mixed explosives are achieved in limestone, which has the lowest values of density and strength characteristics, and the smallest - in granitoids. This can be explained by the fact that, in comparison with quartzite, granitoids have a lower density and lower strength characteristics, but in granitoids, the specific surface energy of cracking is much less at shear cracks, which causes an increase in destruction zones in quartzite;

5) it is established that with the increase of similarity criterion, the relative values of the radii of camouflage cavities, grinding zones and radial cracks for each of the investigated hard rocks are increased;

6) laws of changing the relative radii of the camouflage cavity, the zones of grinding and radial cracks at the explosions in various solid rocks depend not only on the strength characteristics of rocks, but also on the speed and energy characteristics of the cracks formation process;

7) it is established that the values of the parameters of destruction zones in solid rock during the explosions of cylindrical charges of the new blended explosives (exept compolaite GS6) are greater than the values of the parameters of destruction zones in the bursts of the cylindrical charges of standard explosives, therefore the new explosives can be effectively used for the crushing of solid rock in quarries.

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NUMERICAL MODELING OF ZONAL TECHNOLOGICAL FRACTURING IN DECORTIVE STONE QUARRIES

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Abstract

The work is devoted to the solution of actual scientific problems related to the analysis and assessment of the process of technological fracturing of rocks at blocks recessing, development of processing methods that could reduce the formation of fracturing technology.

The thesis proposed a method of rapid diagnosis of the specific fracturing of granite samples from different deposits by using MATLAB. The technique provides a quantitative assessment of specific defects and can be used during examinations of defective blocks and their products.

On the basis of theoretical and experimental studies was established that the margin of the berm’s angle is an area of high stress concentration, which contributes to the intensification of the process of additional microcracks, lags significantly reducing the strength of stone blocks .

The algorithm for the simulation of stress intensity changes in the corner region, depending on the angle of the berm; the technique and software for the analysis of the concentration zones of formation of the critical stress, their patterns of spatial distribution which promotes the developing of separation tecnology of stone blocks from the array were created.

Introduction

Almost a third (200 000 km^2) of the territory of our country is on the Ukrainian crystalline shield, consisting mainly of unique decorative characteristics of granites, diorite, labradorite, gabro and other varieties of rocks. Significant reserves of unique species of rock allow to widely use them for finishing the external surfaces of buildings and structures, interior design, manufacturing and architectural construction products, the construction of memorials, monuments, various sculptures.

Being a leader in the world reserves of ornamental stones, Ukraine occupies one of last places of its production. One of the main reasons is the poor quality of the extracted blocks which do not meet international standards. The structure of export of natural stone in Ukraine shows a significant advantage (more than half) of granite. The decorativeness of the stone fully complies with the requirements of the market, but the use of technologies that do not preserve the integrity of the stone and lead to an active process of cracking inside the blocks, do not allow to cut out plates of European standard sizes. This leads to a decrease in demand for our products and prices. That is why the study of the analysis and evaluation of the process of fracturing rocks by excavation units, as well as the improvement of technological methods, which could reduce the formation of technological fractures, are relevant research trends of the study.

The structure of export of natural stone in Ukraine shows a significant advantage (more than half) of granite.

There is a big difference between sales of granite blocks, or products from these blocks based on the value indicator. By all means, the value share from the sale of products made of granite will be higher than blocks.

Deposits of block decorative stones of Ukraine have favorable mining and geological conditions of bedding, and the small capacity of the mantle rocks and are mined exclusively by open method. During the extraction of rocks from these deposits, the strength properties and the decorative quality of rock should be preserved. Moreover, the determining factor is the size of the extracted blocks due to natural fracturing and equipment, which is used in the extraction.

The natural fracturing of the array presupposes the magnitude of the output blocks of rock mass. The most favorable condition In the mining of natural stone deposits is the presence of a system of three mutually perpendicular cracks. This allows to perform the extraction of blocks of regular geometric shape. When planning mining operations in the decorative stone quarries, fracturing of the array, mined block sizes, physical and mechanical properties of stones are fundamental. And depending on these factors, the direction of the field of mining operations, the height of benches, equipment for production and transportation are being planned.

The basic technological process that changes physical state and the location of the stone, is preparing it for removing. Therefore, many scientific studies, both domestic and foreign scientists are dedicated to this process. The world practice demonstrates many ways of the directed destruction of rocks, providing for the concentration of critical stresses strictly in the required planes of the split or cut stone when preparing for the excavation.

On the territory of Ukraine explosive methods in the preparation of rock to excavation are widely spread. About 55% mining companies use blasting methods. The most common way is blasting with a detonation cord (36%), blasting of low-density ES (14%), gunpowder blasting (5%). 12% is the use of physical and technical methods, the main of which is the cutting of thermo gas-burning burners (7%) and the breaking of the rock with the help of non-explosive destructive agent (5%). The remaining 33 % is the use of mechanical methods, mainly the use of rope sawing (27%) and drilling hydraulic (6 %) method. Recently in mining industry there is a trend to increase the use of mechanical methods in connection with increase of requirements to quality and durability.

A significant contribution to the development of this issue the Zhytomyr school of scientists headed by Professor N. T. Bakka did. Their works show the methods of an estimation of losses of natural stone when using drilling and blasting, drilling hydraulic, thermo-gas flow methods to separate the blocks from the array of natural stone. These methods of the study of the impact of the blasting on the rock were based on comparative analysis studies of the properties of rocks obtained in different ways. To evaluate the effectiveness of forecasting technology of microfracturing stone development from the action of the blasting energy, the pattern of reduction in the strength properties of rocks was studied, that is due to the fact that under the action of blasting loads in the array within a particular zone there are additional deployment, that is a violation of the solidity of stone with cracks.

In the work [1] the dependence of the reduction of the strength properties and development of stone microfracturing from a distance to charge while blasting loads is determined.

In the works [2] a new research methodology of rock boundary zones, affected further stone preliminary milling is described. The works specify that each of the technologies of mining of blocks of natural decorative stone has its effect on their integrity, physical characteristics, decorative features. The damage to the side faces of the block was determined, which is: when the diamond-wire sawing - 24...60 mm; when drilling and blasting technology - 360...440 mm; when continuous drilling out - 50...63 mm; applying thermo-gas flow burners...-124 155 mm; in the process of splitting - 120...250 mm. It is concluded that the least damage the block of natural stone gets when continuous drilling out and wire-sawing. It is proved that microfracturing of block stone quarried by drilling and blasting technologies, decreases with increasing distance from the edge of the block to the middle.

In the works of many authors [3 - 4] it is noted that the method of destruction of rocks during the preparation of the block stone before removal substantially defines the quality of the extracted raw materials and the cost of production. Unfortunately, until today drilling and blasting and drilling hydraulic methods of separating blocks of solid rock are largely used, that negatively affects the quality of raw materials due to the increase of the fracture, reducing the efficiency and increasing the volume of waste in passivation. It is proved that a promising area for extraction of natural stone is the diamond-wire cutting.

The use of diamond-wire sawing in quarries of soft and medium rocks has already found wide application. With the development of equipment design, the use of diamond-wire sawing has begun to spread when drilling hard rock using as a working unit of steel ropes, reinforced with diamond cones.

Characteristics of the destruction process of rocks are determined by the characteristics of their fracturing structure. Physical regularities of origin and development of cracks are the basis of theories of strength of A. Griffiths, E. Orowan, J. Irvin and other scientists.

With the development of thermofluctuation theory of strength of solids, S. N. Zhurkov conducts research of stretching of solids, wherein the destruction of brittle materials occur, and offers the dependencies for determining the durability of these solids from the pressure and temperatures acting on them. The concept of durability is considered as the time from the beginning of load application to the formation of micro-defects [5]. In the works of N. T. Bakka, S. O. Zhukov, R. V. Sobolev the problem of reduction in durability of decorative stones in a modern environment due to the strengthening of the process of crack formation under the aggressive influence of polluted atmospheric air is raised.

The study of fracture of rocks and arrays as a factor in their strength and durability numerous studies of N. T. Bakka, L. I. Baron, B.M. Kutuzov etc. are devoted.

Hierarchy and self-similarity of rock fracture structure determine the necessity of its study at the macro level. A significant contribution to the study of this issue has been made by the scientists of V. Bakul Institute for Superhard Materials. Recent development of electron microscopy led to modern methods of research of processes of crack formation [6, 7]. The ability to obtain images of surfaces of a decorative stone in digital form opens up great opportunities to assess the quality of this material. Using modern calculation methods, it is possible to digitally obtain the concentration value of cracks, their depth, etc. From a scientific point of view, direct interconnection between fracturing and a quality of a decorative stone has already proved; it is indicated that the influence of the aggressive environment occurs in the presence of high concentration of microcracks. Now modern methods of enduring quality assessment of decorative stone are being developed.

Description of the development of rock fracturing

One of the modern methods of electronic processing of photographs of fracturing structure is the use of fractal dependencies to describe the development of cracks in the rocks.

The mathematical apparatus of fractal objects has become the basis for recent methods of crack studying. One of these methods is presented in the works [8, 9], which include fluorescent microscopic method of fixation of coordinates of cracks, computation of fractal characteristics and computer simulation model, to evaluate the real geometry of cracks, the degree of the violation and the specific surface energy of rocks.

Integrated methodology and computer program, which are presented in the works [10], lie in the fact that the study of cracks was carried out using a fluoroscopic flaw detection, adapted to the characteristics of the rock. For further analysis of fracturing structure of rocks, image processing to determine the coordinates of the contour points of the cracks was carried out. According to this methodology the fracture pattern of granite was studied. On the first stage the measuring of the crack size was produced by the classical "mosaic" method where a crack is taken as a linear object in advance.

In accordance with the Richardson law the fracture length nonlinearly depends on the step of measurement δ and can be described by the correspondence

$$L_{\text{фр}} = L_0 \left[\frac{L_0}{\delta}\right]^{d_1 - 1} \tag{1.1}$$

where $L_0$is a linear crack length taken as the distance between its tops μm; $d_1$is its fractal dimension, which determines the real geometry of the crack, δ is the adopted step of measuring the cracks (adopted 10 microns), which corresponds to the resolution of the microscope.

Using the methodology developed by the authors it is possible to obtain a chart of crack distribution of different sizes.

The concentration of cracks with increasing their size naturally decreases and can be described by a log-linear distribution:

$$lnN_i = L_1 - K_L ln(l_i) \tag{1.2}$$

where L_1 is the logarithm of the concentration of cracks of unit length (1 μm); K_L *is* the rate of decline of concentration of cracks with increasing their length.

To determine the fractal dimension of the cracks d_f the method of "coating" is the most simple to implement where the trajectory of the crack is covered with square grids with different face size r_i. However, the coating of each of the hundreds of cracks in the sample set of nets with different face sizes requires a large investment of time and connects with the possibility of errors due to subjective perception of the object. In addition, for the evaluation of destruction of rocks, not only the fractal dimension of single cracks, but also their spatial distribution in the sample is important. All this requires further development of methods for the study of fractal characteristics of fracturing structure of rocks.

Proposed methods and software for analysis of fractal characteristics of fracturing structure of the rocks allow to assess the real geometry of the cracks, the patterns of their spatial distribution, dynamics of development of fracturing structure of rocks. The emphasis in these works is put on the study of the dynamics of development of fracturing structure, therefore, a series of experimental studies of rocks from different deposits was organized. During the sample step loading using the above described methodology photo fixation of fractures and estimation of their fractal characteristics was carried out. To assess the energy characteristics of the process, measuring the deformation of samples was carried out.

It should be noted that during the deformation of samples, along with the development of cracks, their closure and interaction occurs, that is, the cracked structure of rocks changes in general. Interacting cracks form disturbance seats, i.e. clusters [11]. The dynamics of this process can be considered as self-development under the action of the load of the cluster structure of rocks. The process can be represented as a succession of stages in the development of fracture clusters and attach them to each other. Stage sample is shown in Fig. 1 [10].

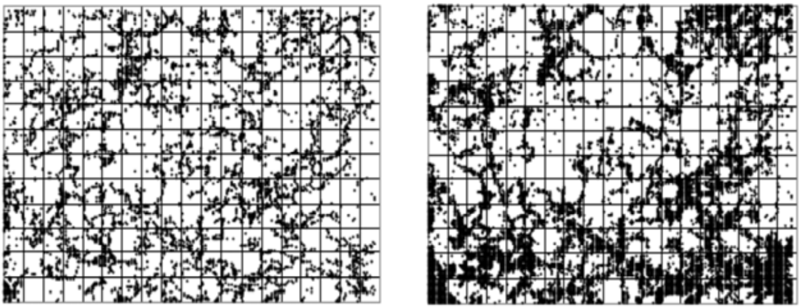


Fig. 1 The formation of cluster structure of violations of rocks

In quantitative form this can be represented through the fractal dimension of clusters, which is determined by the coating method. Analysis of the experimental results in the work [10] showed the nonlinear character of growth of the fractal dimension of the clusters as the sample loading.

Along with the destruction of rocks of crack growth accompanied by a decrease in their modulus of elasticity (average 57%), active in the development of plastic deformation under loads, which is an average of 69% of the destructive voltages.

The results of the research of fractal characteristics of fracturing structure of rocks allow to give a theoretical evaluation of the strength and fracture of the studied rocks.

Increasing demands to the quality of the extracted blocks of decorative stone made the scientists to analyze the nature, regularities of distribution and numerical values of stress fields in the array for further adjustments of technological parameters of separation units.

The process of development of rock pressure and changing stress-strain state of rock mass first actively studied for underground mine workings in the conditions of occurrence at considerable depths [12]. In this case, one of the main initial data for the calculation of stresses and deformations around the excavation is the depth of its location, as the initial voltage in the array are determined mainly by the weight of the rocks above the production.

To determine the stresses in the array at work in the quarries the influence of tectonic forces should be considered. The stress state that exists in the array during fossilization, preserved, and established reltionhips between particles of rocks remain naturally frozen. In determining the stresses in the array, this condition should be considered as zero. Therefore, it is necessary to consider that the stress field of rock massif in the natural state is frozen, but the formation of free surfaces causes the appearance of tensile stresses applied to these free surfaces.

If to conduct research and drill out cores, on the circuit of extended working of circular cross-section this tension acts in the radial direction. To confirm the existence of these stresses in the work [13] the behavior of granite from cores that were removed from array was studied. Within a few days after the extraction to the surface, the samples were expanded. Recorded the acoustic emission signals indicate that there was a formation of microcracks that can be caused by the action of tensile stresses (unloading deformations). The so-called "disking" of the core, i.e. the destruction of core on discs occurs (Fig.2).

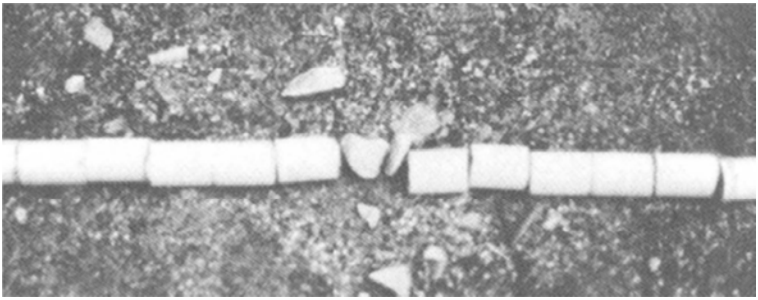


Fig. 2. Disking due to stretching of the cores with a diameter of 5.7 cm from the block 10x10x5,7 m

In the process of separating the block from the array at the quarry, a redistribution of the stress state due to the uploading the individual surfaces takes place. This process is particularly noticeable in the first day and fades within 10 days. Pressure redistribution occurs irregularly and zonal. Certain areas where the values of the unloading technological pressure is more can be separated, which in its turn leads to active formation of technology of microcracks. Surface deformation is the result of disclosure of mi\crocracks parallel to the plane of the natural fracture, which leads to the so-called rebounds. Deflection is a function of the number of new surfaces of the cut in time.

As a result of experimental studies, critical zones were detected on a block where there would be more technological microcracking. Microcracking distribution on the block is uneven.

Thus, in the work [13] it is noted that in recent years deposits of block stone have been involved in the workings, which, together with high decorative value, have rather complicated systems of cracks and stress-strain state. Currently, the question of the block mining in terms of major horizontal tectonic stresses in the array and the subsequent relaxation process of rocks after separation remains poorly studed. In a number of quarries of block stone of the Zhytomyr region there are phenomena of "ejection" of stone pieces from the surface when exposed new horizons of working.

Particularly important thing in this regard is determining the time during which there is an active process of extension of the stone.

The measurement on a block showed a general extension. It was found that deformation took place especially intensively in the first day. After the 1st day in three directions (the first is vertical, the second is perpendicular to the planes of fracture, and the third is parallel to the plane of fracture) it was found that the extension on the 1st day after the extraction was 0.25, of 1.17 and 0.69 mm, and on the 10th day after extraction was from 0.53, 1.91 and 1.55 mm. The authors concluded that the value of deformations is a function of the time of the formation of a new free surface.

In the work [14] analytical calculations of formation of stress fields in the stone blocks extracted from tectonically stressed array are offered. A direct connection of the block sizes and values of accumulated stresses is indicated. It is proposed to eliminate the process of destruction of stone extraction by limiting the sizes of detachable blocks.

After analyzing modern views on the physics of destruction of rocks, it can be concluded that the determining factor is the emergence and development of cracks in the rocks. First, research on the destruction of the solids was based on the Griffith brittle fracture theory, according to which the strength of rocks is determined by the size of the cracks and the specific energy of their surface. These studies of all others emphasized on the most important strength characteristics of brittle solids, i.e. the microfracturing. This formed the basis of subsequent scientific research in the direction of the so-called microdefect theory of strength.

The next stage of development of the theory of strength of solids is characterized by the occurrence of thermofluctuation theory of strength, where the dependence for determining the longevity from the existing stress field and temperature was obtained.

So, based on the findings of modern research areas, it can be concluded that the occurrence of elevated stress field affects the activation process of crack formation in granite. With the rapid development of modern electron microscopy we can obtain images of systems of cracks not only on the surface but throughout the depth. The development of modern methods of fractured evaluation remains.

In recent years a number of researchers use fractal geometry to describe the process of rock-breaking. On the basis of fractal geometry not only the form and structure of the cracks of rocks in quantitative terms are described, but also the direction of their propagation is established. This is a promising analysis method, but it requires the development of authoring software to use mathematical apparatus of fractal theory. In practice, when assessing how ready-made products from a granite and mined blocks the methods for estimating fracture are necessary, which would allow to quickly evaluate the digital image samples, without the costs associated with the application program, and using common software.

The analysis of researches on the question of formation of stress fields in granite massifs shows a dominance of work for deep excavations. The works are submitted, where the question of the peculiarity of the stress field formation is raised and the need for a more thorough study of this question is elicited, that led to the research on modeling of formation of stress fields in the period of the block separation of the array in the quarries of decorative stone for conditions of Zhytomyr deposits in order to identify areas of high stress where an increased technological fracture is more likely to be formed. Simulation of this process can not only indicate the zones of high stresses, but also to help reduce them through a change of technological parameters of separation of the blocks from the array.

The detection of hidden defects in the blocks.

In many works of domestic scientists it is noted that violations of solidity of the stone in the process of its mining dramatically reduces its quality. The factors that affect the quality of decorative stone block are mentioned. They are divided into natural and technological. The factors of natural origin can not be influenced, so scientific researches follow the direction of improvement of technological factors. It is the method of preparing rock to excavation is the main factor of influence on the change of physical and mechanical properties and the presence of defects of a block stone. The choice of preparing method of a block stone to recess specifies ultimately the quality of the resulting products.

To assess the degree of destruction of rock under the influence of method of preparation of the blocks to recess there is a need of analysis of the intensity of the process of technological cracking.

A peculiar feature of the study of decorative facing stone blocks is their uniqueness and value, and therefore, it is possible to test them with destructive methods only once without further application. Therefore the study of changes of the strength properties of the blocks without destruction of rock through the application of modern techniques and equipment is a priority area of research. In recent years, several methods of crack detection have appeared, which allow to perform non-destructive quality control of the stone and its products to detect internal and concealed defects. Based on the fact that the defects change the physical properties of the material, namely density, conductivity, magnetic, elastic properties, etc., the existing methods of flaw detection are based on the study of the physical properties of rocks when exposed to x-ray, infrared, ultraviolet and gamma rays, radio waves, ultrasonic vibrations, magnetic and electrostatic fields and the like. The most common methods of flaw detection of blocks include ultrasonic, color, fluorescent and visual ones.

With the development of modern technical means visual diagnosis of deficiency can be performed by obtaining digital images, which can be further processed.

The presented express diagnostics of the demonstrates rock samples that were extracted with the help of wire-saw blasting technology from Leznikivske granite deposit, Mezhyritske and Kapustyanske deposits. The use of the 5424 Konus binocular microscope and Canon camera helps to obtain pictures of the cracks with 7 times magnification.

Research results are analyzed and indicate that in the investigated samples when applying drilling and blasting technology the damage to the stone in quantity and quality ratio is much more serious. There is a large number of faults of considerable size, which consequently will reduce the quality of the stone.

Application of ultrasonic methods in the study of rocks allows to expand considerably the range of issues associated with the study of the physical properties and structural features of rocks. The main issue that can be successfully solved with the help of ultrasonic methods of study of rocks is to study internal structure of rocks and its relation to acoustic characteristics, the influence of the internal structure of rocks on the anisotropy of properties and other issues. As a physical characteristic, the research adopted a speed of propagation of longitudinal waves in rock samples.

With the improvement of technological progress improved hardware capabilities appeared, and this contributes to the further perspectives of its development as one of the most effective non-destructive methods in the study of the internal structure and mechanical properties of rocks. To perform this work ultrasonic flaw detector from the Italian company MATEST model C372N was used.

This device is designed for detection of defects, cavities, small cracks in decorative plates and blocks, and control due to the influence of environmental factors.

The device also provides the functions of measuring the time necessary to the signal traveling from the ultrasonic transmitter through the selected material to the sensor-receiver, calculating the speed of the passage of the ultrasonic impulse or signal through the material (at a given distance between transmitter and receiver), calculating the distance between the receiver and the transmitter (at the specified pulse speed) through the selected material, calculating elastic modulus (at a given distance between the transmitter and the receiver).

It is possible to obtain the degree of compression during testing, attached ultrasonic flaw detector to digital soft hammer model C386N.

In the presented studies granite samples were analyzed that were cut from the blocks using two different technologies – explosive and diamond-wire cutting from three deposits (Pokostivske, Kapustyanske, Kornynske). Samples were investigated by ultrasonic waves using the ultrasonic flaw detector C372N according to three parameters: the time of the wave traveling, speed, elastic modulus.

As a result of application of the dynamic method of determining the deformation properties of the studied granite samples the dependences of change of elastic modulus at different methods of separation were obtained. As noted, one of the main factors determining the properties of rocks and reference faults, is fracture.

Dynamic modulus of elasticity and Poisson's ratio are the determining elastic characteristics of materials. Depending on whether the modulus of elasticity in samples increase or decreases the concentration of fracturing in the rock changes.

As a result of experiments, the following results are obtained: of all deposits of granite, which were investigated, the highest values of modulus of elasticity are in the samples, which were selected from blocks, separated with the use of diamond-wire technology. The obtained experimental data in combination with empirical formulas allow to determine the strength characteristics of the blocks. And therefore, we can conclude that with the increase of the strength characteristics leads to the increase of the life of these units and durability of such units will also be higher.

Through the use of modern ultrasonic flaw detector, the assessment of the quality of block products can be done not only at the edges of the blocks, but through the entire block giving a complete assessment of a product quality.

Microscopic method is widely used in various industries and allows to study the structure of microscopic objects. The basis of the microscopic method is based on light and electronic microscopy. Depending on the object properties physical properties of light are changing, i.e. its color and brightness associated with length and wave amplitude, phase, plane and direction of wave propagation. Various microscopic research methods are based on the use of these properties of light.

Microscopic method was applied to assess natural stones fracture. This was done using the stand consisting of LomoMetam R-1 microscope with a CCD digital camera KOSOM (Fig. 3).

On the first stage of the measuring of the crack size data was processed by the classical "mosaic" method where a crack is taken as a linear object in advance. The results are shown in Fig.4.

With a help of a microscope the area of 2×2 cm was chosen on the samples and cracks were detected. For further analysis of fracturing structure of rocks, image processing to determine the coordinates of the contour points of the cracks was carried out. The fracturing structure of granite was studied using the capabilities of CorelDraw and Microsoft Excel.

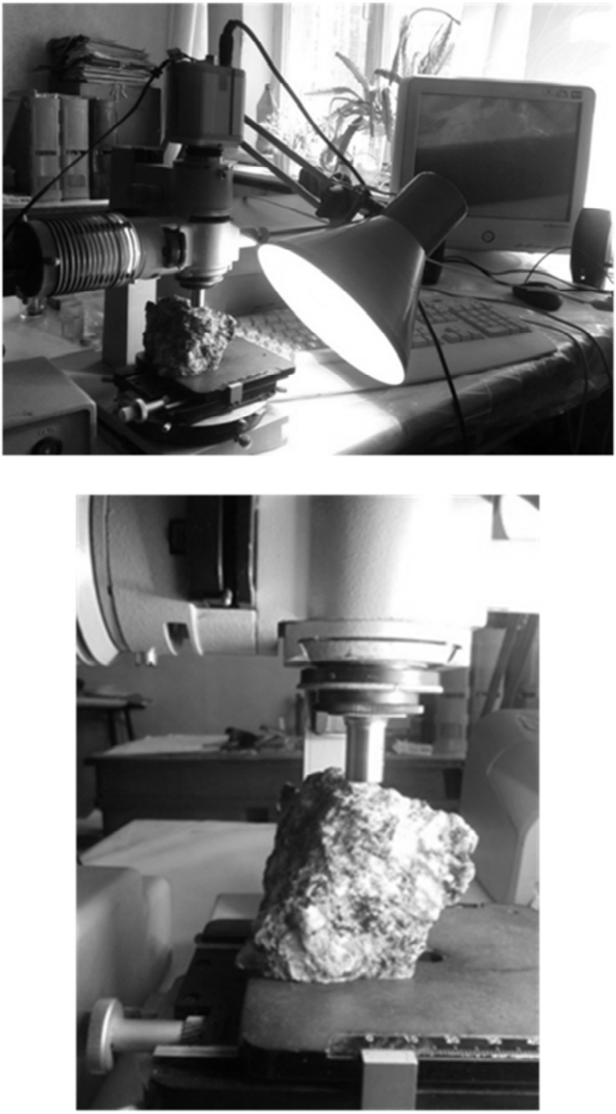
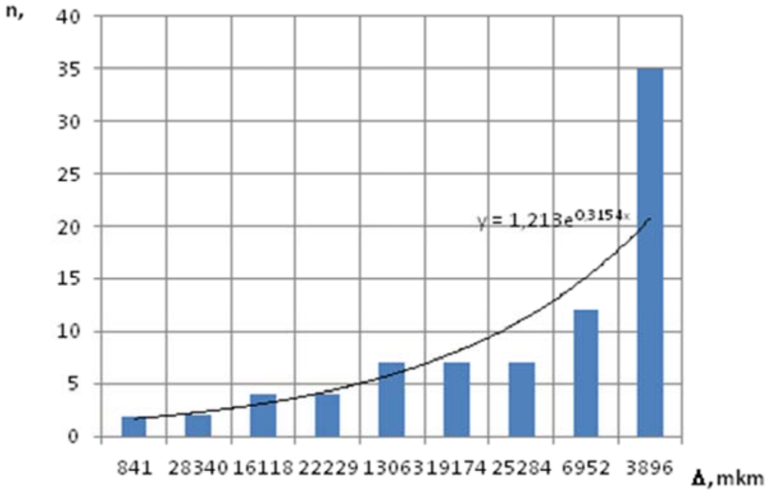
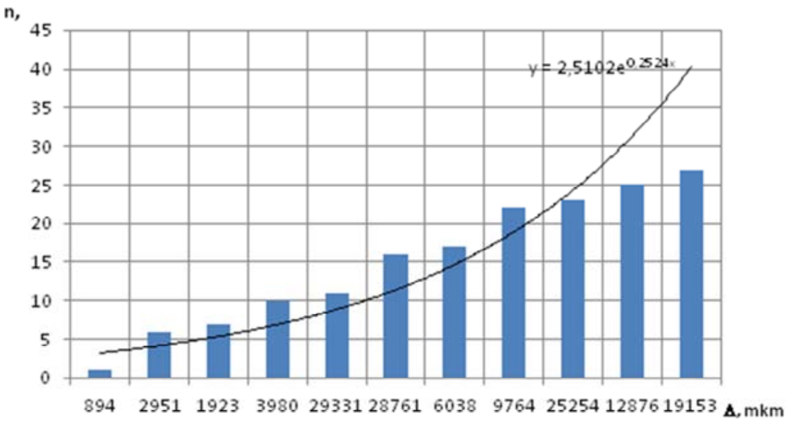


Fig. 3. Image of the stand which was used in the work



a)



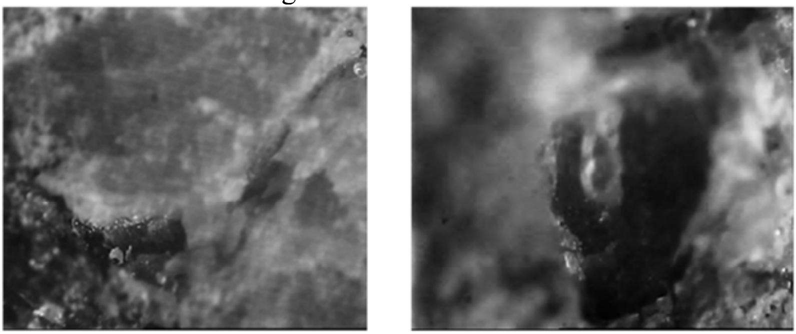
b)

Fig.4. Distribution of number of cracks depending on their size a - the method of production with the use of the wire cut; b – the method of production using blast.

The work [6] stated that the real strength of rock depends on the size and number of defects and cracks. This is due to the existence of high levels of stress in the vicinity of crack tips compared with the voltage for the isotropic medium and the interaction of adjacent cracks. In the presence of a large number of natural stress concentrators (microcracks) in the rock sample destruction by the method of stretching under bending can occur at any point. For destruction of samples of rock in a given cross-section in the work [10] incisions of different sizes were artificially created. The assessment of strength of granite samples with artificially created incisions was taken, and comparison of experimental data with classical theoretical approaches of Griffiths, Naber, Savin before the development of stress concentrators was performed. The author of the work [10] argues that the best agreement between calculated and experimental data is the method of calculating of Savin.

Thus, a complete picture of the analysis of changes in technological microfracturing is possible to obtain not only assessing the length of the microcracks but also their depth. It was found that the maximum value of the crack depth for samples obtained using explosive technology, achieves 900 μm, while the wire-cutting is the maximum of 150 microns (100 microns is 0.1 mm), Fig. 5 shows the resulting images of the crack depth under different methods of production.

Extraction method with the use of wire sawing | Extraction method with the use of blast



70 μm | 900 μm

Fig. 5 The depth of the cracks at various mining methods

The influence of the method of separating a block of stone from the array is characterized by the dependence of the concentration of microcracks. The dependences of the size of cracks from their number are obtained in the work.

As a result of dynamic loading of the blast in the rock, the setting change of microfracturing due to active process of expansion of already existing microcracks and the formation of new ones is observed. On the basis of experimental research, graphs of the size dependence of cracks on their quantity are constructed. The number of large cracks when extracting natural stone with the method using the blast are 2 times more than with the method of wire-sawing. The depth of the cracks when using the wire-sawing is in the range from 70 μm to 150 μm, whereas the use of blasting method is up to 900 μm.

As a result of the research and determining the dynamics of changes of the modulus of elasticity it was determined that the method of preparing the blocks for the separation affects the dynamic modulus of elasticity. When applying a less destructive method using wire-sawing, the value of the dynamic modulus of elasticity is 20% higher than values of the same modulus of elasticity in blocks separated by blasting. Therefore, it can be argued that the qualitative characteristics of the blocks of decorative stone, its strength properties is 20% higher than in blocks separated by a wire-sawing.

Assessment of technological microfracturing of granite blocks

Microscopic method of measuring technological microfracturing is quite time consuming and takes a considerable amount of time. Thus, the selection of flexible, comprehensive and well-documented environment for digital image processing is a key factor that affects the quality of the final result. The samples of granite used for studies were produced by drilling and blasting method and with the help of wire saws from the Mezhyritske and Leznykivske deposits. As a result, using the scanning electronic microscope the images were obtained which are shown in Fig. 6.

Conducting a visual examination, it can be stated that the use of drilling and blasting method to separate the granites leads to the formation of the rock cracks of considerable size, the damage of stone in quantitative and qualitative ratio is much higher, which in its turn correspondingly reduces the quality of the block stone.

But it is impossible to evaluate this process quantitatively, to conduct a rapid diagnosis of finished products from stone, and block samples of products to determine the percentage of deep cracks with the establishment of specific concentration of fractures according to the images.

For the analysis of photographs image segmentation on the basis of saturation of the black color in the image was performed. With this aim, the image was presented in the form of the function $f(x,y)$. Images appear as dark objects on a light colour. In this case, the black colour shows deep cracks in the sample. The analysis of the samples was performed on the basis of the intensity of the black colour. The means of object detachment from the surrounding background was to select a boundary of T that separates the two pieces of brightness. Any point (x,y) which $f(x,y) \geq T$ will be called a point object. If it does not meet this condition, it belongs to the background point. In other words, the image $g(x,y)$ obtained due to the limit of processing can be represented as:

Name of a deposit | The method of preparing to excavation

Drilling and blasting | Wire saw

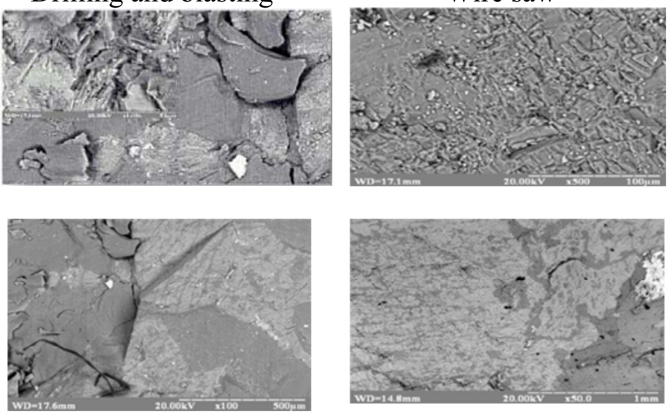


Fig. 6. Image samples of the granites as a result of analysis using scanning electronic microscope REM-106I

$$g(x,y) = \begin{cases} 1 \ at \ \ f(x,y) \geq T \\ 0 \ at \ \ f(x,y) < T \end{cases}$$

A global description is obtained by integrating the largest black clusters on the images. As a result, a histogram is obtained which allows a quantitative value to estimate the percentage of faults on the samples. Fig. 7 and 8 present the histograms after the statistical processing of the images Fig. 7 using MATLAB program.

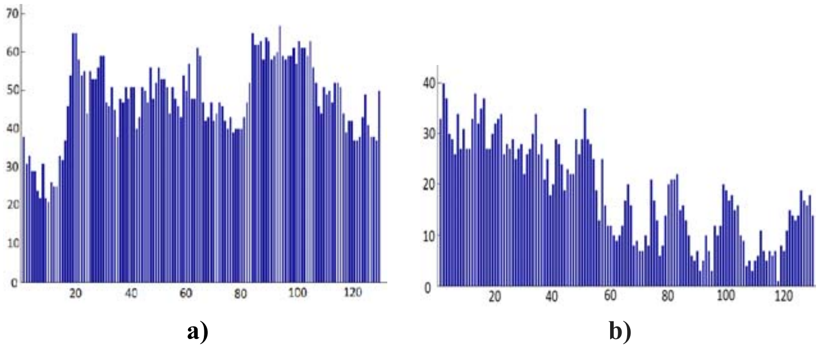


Fig. 7. Histogram of statistical processing of the granite sample from Mezhyritske deposit, separated by: a - drilling and blasting method; b - wire-sawing

The new method of express diagnostics for the evaluation of the specific concentration of fracturing technology, depending on the method of preparation of stone blocks to the excavation showed that for samples from Mezhyritske deposit the concentration of fracture in the application of drilling and blasting technologies is 57 %, while wire-sawing it is reduced to 22 %.

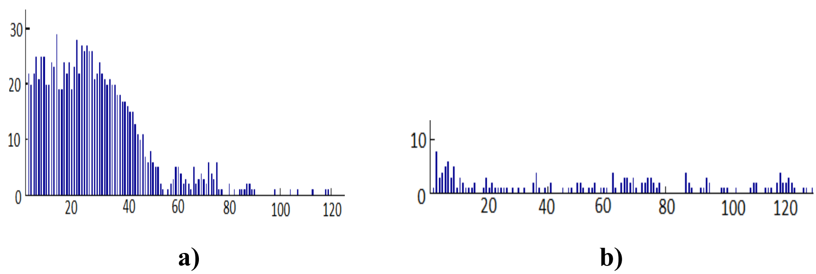


Fig. 8. Histogram of statistical processing of sample of granite from Leznykivske deposit, separated by: a - drilling and blasting method; b - wire-sawing

For Leznykivske deposit the concentration of the fracture is, respectively, 21 % and 5 %. Comparing the results of classic microscopic research method with the proposed method, it can be noted that they are the same but the conduction of this diagnosis is less time consuming.

Modeling of zonal technological fracture

Along with the creation of new technologies of destruction that are based on non-traditional solutions (thermodestruction, the effects of streams of high-energy particles and more) the main way to improve basic technologies of the separation of a block stone from the array is to study the stress-strain state, physical-mechanical properties of the rock, brittleness of rock which depend on the structure, mineralogical composition and crystal orientation, as well as the size and shape of the body, that is destroyed, and also the stress and deformation rate. This is due to the fact that the interaction of the main structural fields in the array, i.e. fields of multi-scale damage and stress fields largely determine the strength and durability of any natural and natural-technical objects, as well as the dynamics of the process of destruction.

Since the fracture causes additional reduction of the durability of the material in the process of operation, the modeling process of the formation of zones of technological fracturing and development of ways to reduce these zones are of vital importance.

When conducting experimental studies it is noted that the change of the stress state in array from the separation of the blocks leads to its redistribution and formation of tense zones. Analysis of the results reveals a region of stress concentration in the inner corner of the ledge, which is a dangerous area, where the rock is subjected to deformation, the values of which can exceed the tensile strength. As penetration in the array increases this concentration rapidly declines. It is particularly noteworthy the appearance of the stretching tension, that is the most dangerous for the granitoids. To model this process the mathematical problem statement is made and the algorithm using finite element method (FEM) is developed. Therewith the boundary problem of elasticity theory in the plane-strain deformation with use of Mathcad package was solved.

The use of finite element methods for the solution of problems of geotechnical engineering allow to formulate practically convenient methodology for solving complex differential equations of mechanics of solids deformation [16].

As a result of the numerical simulations results obtained for a specific granite coincide with the experimental results on the formation of the strained areas in the corner of the ledge. If the value of the working angle of the ledge 90^0 shear stresses τ_{xy} become maximum values in compression are 7.24 MPa, and the maximum values of tensile of 7.38 MPa. For the granites in which the bending strength is 18 MPa, tension areas with these values of the tangential stresses lead to the active process of cracking with a corresponding decrease in the qualitative characteristics of the extracted blocks.

The use of technological methods, which will reduce the working angle of the bench on 10^0, will allow to reduce the tangential compressive stress in the corner areas from 7.24 to 1.19 MPa, and tensile from 7.38 to 3.69 MPa. Accordingly, the process of formation of technological fracturing is being reduced that allows to obtain blocks of large size thereby increasing the efficiency of extraction of block stone in the quarries.

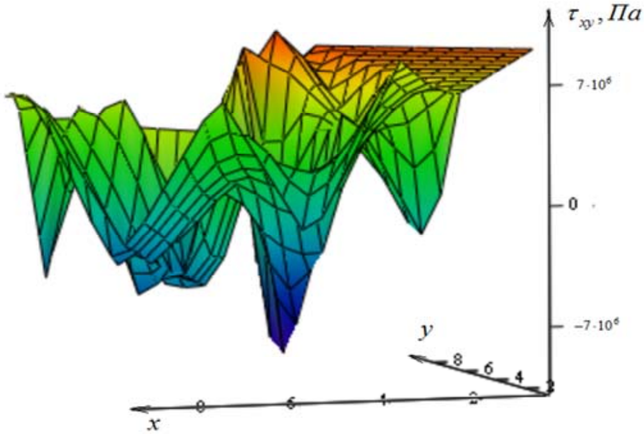


Fig. 9. The distribution of shearing stresses τ_{xy} in the value of the angular zone 90^0. The maximum value is 7.24 MPa, minimal value is 7.38 MPa

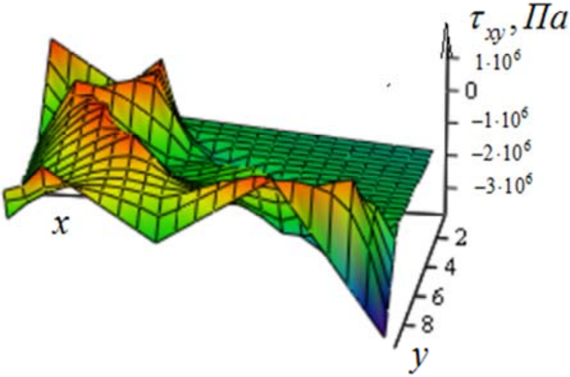


Fig. 10. The distribution of shearing stresses τ_{xy} in the value of the angular zone 80^0. The maximum value is 1.19 MPa, minimal value is 3.69 MPa

It is established that by reducing the angle of the slope, the intensity of the formation of zonal stress is reduced. Changing the angle of the ledge, it is possible to adjust the dynamics of the process of crack formation in the process of separation of the blocks from the array.

The most critical, from the point of view of process of intensification of granitoid cracking, is the tensile stress that occurs when partial unloading of the ledge takes place. By increasing unloading stress in the corner areas the deformations, which constitute 40-50% of the maximum critical strain of fracture of granite under one load tension are made. It is possible to explain the decrease of the strength characteristics in the corners of the blocks due to the formation of such zonal technological microfracturing. The developed methodology and software for analysis of formation of the concentration of critical stresses and regularities of their spatial distribution can become the direction of improved technologies for the separation of block stone from the array. Increasing the angle of the bench on 10^0, zonal tensile stress can be reduced twice and thereby the quality of the extracted blocks can be improved.

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INFORMATION RESOURCE-SAVING TECHNOLOGY OF EXTRACTION, TRANSPORTATION AND UTILIZATION GASES OF COAL MINE

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Abstract

The idea of work consists in application of the established safety criteria, the developed structural and functional scheme and the selected complex software and technical manager to meet the requirements of labor protection, explosion safety and reduce emissions of toxic, greenhouse gases into the atmosphere of a single, resource-saving, information process for extraction, transportation and utilization of coal mines.

The object of the study is the processes of increasing safety, efficiency and resource conservation in the extraction and utilization of coal mines gas.

Subject of research - the laws of safe, trouble-free and efficient operation of the equipment of a single technological process in the extraction, transportation and disposal of coal gas mines.

Methods of research - analytical studies and expert assessment of the scientific research results on the explosiveness of methane-air mixtures and the emissions reduction of toxic substances during their combustion, the method of signature mathematics for solving boundary value problems in information management systems, the method of heuristic and constructive search for new solutions, the method of experimental research in industrial conditions.

The aim of the work is the development of scientific and technical fundamentals of labor protection, explosion safety, efficiency and reducing the negative impact on global climate change of a single information-dynamic resource-saving process in the extraction, transportation and utilization of coal mine gases.

The main results of the research are as follows:

Criterion of explosion-safety methane-air mixtures are analytically justified and established for safe management of the excavation and

degassing of isolated mine workings, from which the extraction of mine methane is extracted, as well as for the safety of its transportation and preparation at a gas-mixing station for utilization.

The structural and technological scheme of a single information-driven resource-saving technological process for extracting, transporting and utilizing the gases from a coal mine has been developed.

A criterion has been established for the effective management of the fuel-air ratio in the controlled moderate non-combustion regime, which ensures reduction of toxic gas emissions to the premises of the utilization station and to the surrounding atmosphere, as well as greenhouse gas emissions of methane and carbon dioxide.

Requirements are formulated for system-wide solutions and information support for the software and technical complex (STC) for the information management of the extraction and utilization energy-saving technology of coal mine gases and proposed for their implementation and approved in the conditions of long-term industrial operation the STC based on OpenSCADA "DIA".

1. INTRODUCTION

Ukraine has a significant raw material base of coal, which is sufficient up to 450 years of intensive production. According to the results of the M.S. Polyakov Institute of Geotechnical Mechanics, National Academy of Sciences of Ukraine of 2017, the gas reserves of coal fields in Donbass exceed 3 trillion m3. This is the basis of Ukraine's energy independence.

In the works of academician A.F. Bulat, doctors of technical science: B.V. Bokiy, I.A. Efremov, E.L. Zvyagilsky, K.K. Sofyisky, V.G. Perepelitsa, L.E. Filimonov was developed a scientific and technical basis for the extraction, transportation and utilization of gases from coal deposits with the help of mining cogeneration power complexes. The construction of such complexes will ensure the reliability of electricity and heat supply to coal-mining enterprises, as well as adjacent residential areas and enterprises. At the same time, the consumption of imported natural gas will be substantially reduced by replacing it with mine methane in heating gas boiler houses and there will be no need to purchase electricity from the mine. The positive accumulated experience in European countries in the utilization of methane of closed coal mines [1] indicates that, with the current decline in coal mining in Ukraine by state-owned mines, it is advisable to reduce the costs of airing coal mines that do not participate in the extraction of coal, degassing and utilization of methane. However, the scientific and technical basis for the safety and effectiveness of these works need in-depth development. To solve the above-mentioned urgent problems, it will be necessary to create a single information and control complex for underground and surface extraction of coal mine gases, their transportation and utilization in real time. Thus, the establishment of regularities determining the explosion-proof boundaries of the ratio of the concentration of oxygen and methane in the extraction of gases from isolated mine workings and degassing wells, during their transportation by gas pipelines and in preparation for utilization at gas mixing regulatory points; the formation of toxic gases in the furnace from the excess air factor when burning gaseous fuels is a topical scientific problem, the solution of which will allow developing technical fundamentals of labor protection in the extraction, transportation and utilization of coal gases.

2. BASIC TEXT

2.1. Substantiation of the explosion safety criteria for the extraction and utilization of coal mine gas

Analysis and expert evaluation of achievements in the field of study, theoretical and experimental studies of the explosiveness of methane-air mixtures, cited in [1, 2, 3], relate to the following.

In order to create a fiery or explosive combustion of methane, it is necessary to mix the initial components in certain proportions, i.e., the formation of a combustible mixture. If the concentration of combustible components in the air is below the lower limit of inflammability (explosive), (LLI), then the mixture is not flammable. But in addition to the LLI, there is another limit, affecting the flammability - a decrease in the concentration of oxygen in the environment in which the combustible gas is located. This concentration is called the limiting concentration of oxygen (LCO), and the process remains safe, even if the concentration of combustible components in the medium is significantly higher than their LLI. The reaction of methane ignition looks like this:

$$CH_4 + 2\ O_2 ==> CO_2 + 2\ H_2O \qquad (1)$$

In other words: for the oxidation (burning) of one molecule of methane, we need two molecules of oxygen. Therefore, for oxygen, the stoichiometric coefficient is 2, and the LCO is equal to the methane LLI increased by two times.

In practical conditions of gas combustion, oxygen is taken not in pure form, but enters into the composition of air. Since air consists of 79% of nitrogen and 21% of oxygen, each volume of oxygen requires 100/21 = 4.76 volumes of air or 79/21 = 3.76 volumes of nitrogen. Then the combustion reaction of methane in air can be written as follows:

$$CH_4 + 2O_2 + 2*3{,}76N_2 = CO_2 + 2H_2O + 7{,}52N_2 \qquad (2)$$

It can be seen from the equation that 2 m^3 of oxygen and 7.52 m^3 of nitrogen or 2 + 7.52 = 9.52 m^3 of air are required to burn 1 m^3 of methane. LLI and LCO are graphically presented in the diagram of the explosiveness of methane-air mixtures (fig. 1). From this diagram it follows that all practicable mixtures of methane with atmospheric air are represented by an area below the *AL* line. Point *B* corresponds to the lower concentration limit for the explosiveness of methane in air (5% methane and 95% air), and point *C* - upper (upper limit of flammability, 15% methane and 85% air). Point *D* corresponds to the lower concentration limit of the explosiveness of the mixture in oxygen of the (LLI - 6% for methane and 2% for oxygen for LCO). Points *B*, *C* and *D* close the contour, called the triangle of explosiveness, within which the methane-air mixture is explosive. The line *BD* is the line of the lower lines, and the line *CD* - the upper concentration limits of explosiveness. The area bounded by the *AGOA* contour forms a zone of non-explosive mixtures of methane with air oxygen, and the region to the right of the *CD* line, limited by the *DHMC* contour, is a zone of non-explosive mixtures of methane with air oxygen, but which can become explosive when the oxygen concentration exceeds 12%.

Based on the analysis of the diagram (figure 1) and the safety coefficients adopted in [1], we made a conclusion on the possibility of increasing the resource saving of mine methane with concentrations below 25% by regulating the release of the volume of its extraction into the atmosphere, taking into account the explosion safety limits determined by the ratio of the simultaneously measured concentrations of oxygen and methane, and at the same time, part of the mixture of the ALNOA area, in figure 1, is not released into the atmosphere. As be obvious from the figure 1, the area bounded by the AIKLSOA lines is separated from the explosive triangle BCD on the right more than 10% by methane (LK boundary), 5% below the lower ignition limit (explosive) for oxygen (IK boundary) and left border AI is located in the explosion-proof zone. Based on the above, we recommend the methane-air mixture of the AIKLSOA area with parameters below the AIKLS limits to be defined as explosion-proof and to use it for extraction, transportation, storage and disposal.

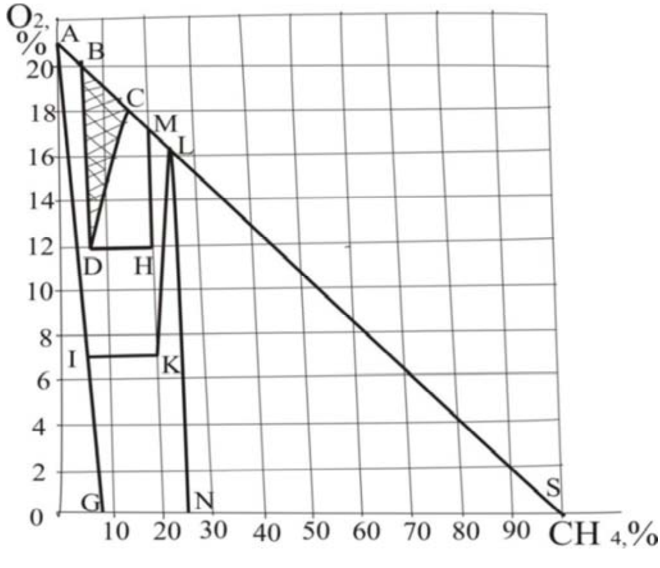

Fig.1. The diagram of explosive methane-air mixtures

The results of the analytical studies presented in the diagram (figure 1) indicate that in the range of methane concentrations from 0 to 5%, the oxygen concentration value determining the explosion safety of the methane-air mixture is inversely proportional to the methane concentration in the range of methane concentrations from 20% to 25%, that is directly proportional to the methane concentration, and at an oxygen concentration below 7%, the mixture does not ignite and does not explode under normal conditions of pressure and temperature. This regularity provides a basis for establishing a safety criterion for the excavation and degassing of insulated mining workings, for the extraction of mine methane from insulated mining workings, for transportation by degassing pipelines and in preparation for utilization in gas mixing units in the form of equations (3), (4) and (5):

Boundary (*AI*) from 0% to 5% CH_4

$$K_{б1} = \frac{7 + \left|K_{CH_4} - 5\right| \cdot 2{,}6 - K_{O_2}}{7 + \left|K_{CH_4} - 5\right| \cdot 2{,}6} \cdot 20^{0{,}5\left[1 - Sign\,(7 + \left|K_{CH_4} - 5\right| \cdot 2{,}6 - K_{O_2})\right]}, \quad (3)$$

Boundary (*IK*) from 5% to 20% CH_4

$$K_{б2} = \frac{7 - K_{O_2}}{7} \cdot 20^{0{,}5\left[1 - Sign(7 - K_{O_2})\right]}, \quad (4)$$

Boundary (*KL*) from 20% to 25% CH_4

$$K_{б3} = \frac{20 + (K_{CH_4} - 20) \cdot 1{,}6 - K_{O_2}}{20 + (K_{CH_4} - 20) \cdot 1{,}6} \cdot 20^{0{,}5\left[1 - Sign(20 + (K_{CH_4} - 20) \cdot 1{,}6 - K_{O_2})\right]}, \quad (5)$$

where: $K_{б1}$ – explosion-proofness factor for boundary *AI*; $K_{б2}$ – explosion-proofness factor for boundary *IK*; $K_{б3}$ – explosion-proofness factor for boundary *KL*; K_{CH4} – measured concentration of methane, %; K_{O2} – measured oxygen concentration, %.

Equations (3, 4, 5) are obtained by the methods of signature mathematics for solving boundary value problems in information-controllable spaces of technological processes.

2.2. Structural-functional scheme of resource-saving extraction and utilization of coal mine gases

Establishment of a safety criterion in the case of gasification and degassing of isolated mine workings and justification of the choice of technical means for its implementation allowed the development of a structural and technological scheme for degassing and utilization of coal mine methane (MM), coal gas (CG) recovered by surface degassing wells, and methane ventilation jets (MVJ), presented in fig. 2.

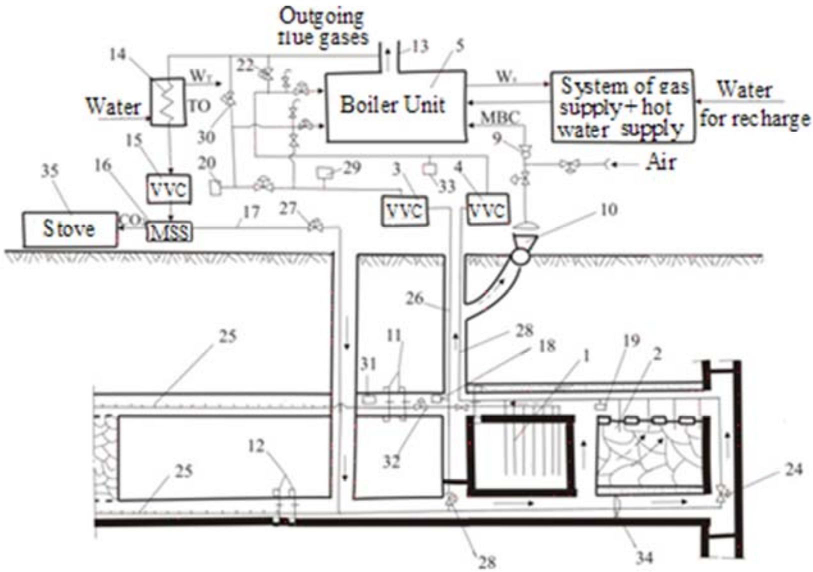

Fig. 2. Structural and technological scheme of degassing and utilization of coal mine methane

The degassing system of the lava excavation section is represented by the leading wells 1, of which the mine methane with a CH4 concentration of more than 40% is supplied to the lower stage of the boiler unit 5 burners with the help of the VVK-3 vacuum-vortex compressor. On the lower stage of the burners there is also coal gas with a methane concentration above 92% recovered by surface wells [3] with the valve 20 opened. Vacuum-vortex compressor 4 on the upper stage of the boiler burners coal mine methane is fed with a concentration of less than 30%, aspirated from the waste space by sprockets 2. The boiler unit during the combustion of coal mine methane heats the water in the system of heat and hot water supply (HWS). In boiler 5, together with air, a part of the methane emanating from the ventilation jet shaft is also burned, which is supplied to the furnace of the boiler by means of a fan 9 sucking off part of the air emanating from the mine under the influence of the depression created by the fan of the main airing 10.

At the same time, methane release into the atmosphere is decreased, which is one of the most dangerous greenhouse gases.

Additional mining of coal mine methane is prepared and carried out as follows: with the help of two locks equipped with remotely controlled regulators of mine air streams 11 and 12, all the workings of one wing of the mine are insulated. The design of the regulator is described in [4]. The regulator of the shaft air flow (Fig. 3) is mounted in the mine in the bridge 3 and includes a vent 1 for people and for remote control of the air flow in the mine. The doorway 2 serves to pass the electric underground transport.

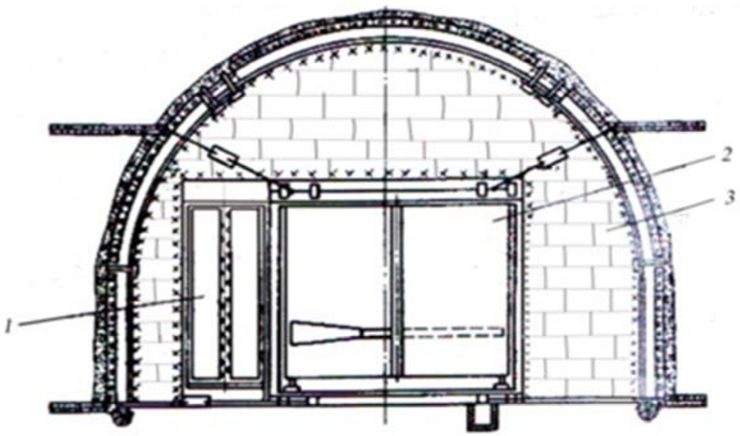

Fig. 3. Mine air flow regulator:
1- ventilation door for people passage and air flow regulation;
2 - door for transport passage; 3 - wall.

Adjustment of air flow is carried out by changing the installation angles of the vent windows. The relative air flow $К_{pi} = Q_{max}/Q_i$ is described by expression

$$Кр = 2{,}25б12 – 1{,}98·10\text{-}2б1 + 0{,}23, \qquad (6)$$

where: $К_{pi}$ – relative air flow in the i-th position of the leaflets; Q_{max} - maximum air flow in production, $м^3/с$; Q_i- air flow through the regulator in the i-th position of the leaflets, $м^3/с$; $б_1$ – angle of installation of valve flaps, degrees.

In order to control the flow of inert gases, gas analysis and regulation points are offered with safe gassing and degassing of the outcroppings, with the use of relay regulators common at the dawn of the development of automation. By its spread, relay systems are required not only for the simplicity of the design of the regulators, but also for the independence of the regulator settings from the parameters of the control object, its inertia, disturbing influences and operation modes [4]. It is these properties that make such systems indispensable for the uncertainty of the parameters of the control object, the nonlinearity of their characteristics, the rapid change in their operating modes and the operating conditions of the system [3].

The measurement of oxygen concentration should be performed by a gas analyzer with a relative reduced error not exceeding 0,2%, methane concentration in the range from 0 to 5% with a relative reduced error of measurement not exceeding 0,2%, and in the range from 5 to 100% with a relative reduced error of measurement, not exceeding 2%.

To achieve the explosion safety of a single technological process for extraction and transportation of coal mine methane, the proposed safety criterion proposes the supply of inert gas-nitrogen to methane-air mixtures. It is obtained with the help of a membrane separation plant from the cooled flue gases of the utilization system. A part of the outgoing flue gases (OFG) (fig. 2) from the chimney 13 is passed through a heat exchanger (HE) 14 with a vacuum-vortex compressor (VVC) 15, where moisture is drawn from the OFG, and the dried gases are fed to a membrane separating station (MSS). In MSS, the separation of OFG into nitrogen (N_2) and carbon dioxide (CO_2) takes place.

Carbon dioxide (greenhouse gas) is sent to a greenhouse where it is absorbed by plants, while its negative impact on global climate change is reduced.

The inert gas, nitrogen, under the pressure created by the VVC 15, is fed through the pipeline 17 to the isolated, with the help of the locks, the development of the non-working wing of the shaft. At the same time, a methane-air mixture is sucked from isolated mining workings with the help of pipeline 25 and the VVC 3. When the concentration of oxygen in the main pipeline 26 (K_{O2}) is 7% or lower and the methane concentration is more than 5%, the nitrogen supply to the isolated mine workings is stopped by means of a remotely controlled valve 27. The oxygen and methane concentrations in the pipeline 28 are controlled by the gas analyzing station 18, which, with the help of the controller, calculates the safety criteria by equations (1), (2) and (3). When the mine workings are degassed, equation (1) calculates the value of the explosion-proof criterion of the methane-air mixture in the cavity of the mine wing. The valve 27 is supplied with nitrogen supply, and the gate valves of the gateway 12 ensure explosion safety of the mine atmosphere until the methane concentration decreases to 0,75 % and oxygen increases to 20 % and is maintained at this level continuously.

2.3. Provision of labor protection requirements in the process of utilization of mine gases

During combustion of gases in coal mine toxic gases are generated, the most dangerous of them is a nitrogen oxide (NO) - a colorless gas, when it enters the station premises at ordinary temperature, NO is combined with oxygen to form NO2 nitrogen dioxide. As you move away from the source of the release, an increasing amount of NO is converted to NO2, a brown gas with a characteristic unpleasant odor. Nitrogen dioxide strongly irritates the mucous membranes of the respiratory tract. Getting into the human body, NO2 on contact with moisture forms nitric acid, which corrodes the walls of the alveoli of the lungs. In this case, the walls of the alveoli and blood capillaries become so permeable that they pass the blood serum into the lung cavity. In this liquid, the inhaled air dissolves, forming a foam that prevents further gas exchange. There is swelling of the lungs, which often leads to death. Prolonged exposure to nitrogen oxides causes the expansion of cells in the roots of the bronchi (thin branching of the airways of the alveoli), deterioration of the resistance of the lungs to bacteria, and the expansion of the alveoli.

In Ukraine, the following environmental standards for the content of nitrogen oxides in the atmospheric air of premises and populated areas have been established: for NO_2, the maximum one-time maximum permissible concentration (MPCm.s.) is 0,085 mg / m^3, and the average daily maximum permissible concentration (MPCa.d.) is 0,04 mg / m^3; for *NO* - MPCm.s = 0,4 mg / m^3, MPCa.d. = 0,06 mg / m^3.

Carbon monoxide – is a colorless, extremely toxic gas without taste and smell, lighter than air (under normal conditions). Chemical formula - *CO*. Carbon monoxide is dangerous because it does not smell and causes poisoning and even death. Signs of poisoning: headache and dizziness; there is a noise in the ears, shortness of breath, rapid heartbeat, flickering before the eyes, redness of the face, general weakness, nausea, sometimes vomiting; in severe cases, convulsions, loss of consciousness, coma. The limiting threshold concentration of *CO* in closed rooms is 25 ppm (29 mg / mi). Concentration in the air of enclosed premises more than 0,1% leads to death within one hour.

The main reasons for the occurrence in the air of boiler rooms of high levels of carbon monoxide, nitrogen oxide NO, nitrogen dioxide NO2 are disturbances in the fire in the furnace, which can occur as a result of the following circumstances: uncoordinated work of the fan and exhauster, fluctuations in the rarefaction in the boiler furnace due to disturbances of the process of fuel-air mixture mixing, the appearance of leaks of poisonous gases from pipes and other elements of boilers heating surfaces, economizers, gens and regulators of the ratio of pressure "gas-air" and rarefaction in the furnace. The most toxic are emissions of nitrogen oxides, which first of all makes it necessary to reduce their formation in the furnace when burning fuel. The main factors affecting the yield of thermal nitrogen oxides are: the temperature in the NOx generation zone, the concentration of atomic oxygen, and the residence time of the combustion products in this zone. The effect of the excess air factor (alpha) on the formation of NO in the furnace of the boiler is represented by the NOрк diagram in fig. 4, obtained as a result of routine commissioning tests of the boiler unit No. 2 of the BKZ-220-100 type (40).

The dependence of NOрк emission concentration (mg/m3) on the steam load of the boiler unit Fп (t/h) according to the commissioning tests regime chart is represented by the NOрк diagram in fig. 4. In [6, 7] it is proposed for reduction the formation of NOx when burning gaseous fuels in boilers controlled, moderate incomplete combustion of fuel in the range (alpha) from 1.04 to 1.1.

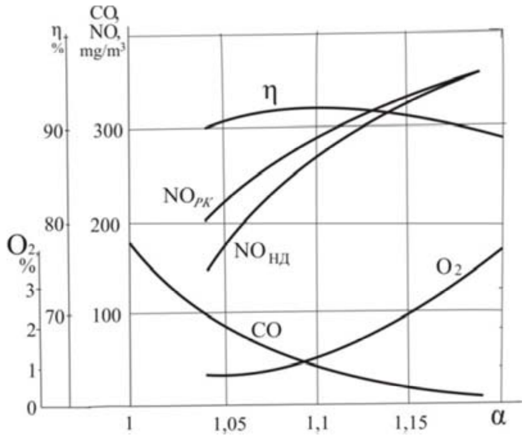

Fig. 4. Dependence of the content of O_2, *NO*, *CO*, on the coefficient of excess air *б*

The results of experimental studies of this regime in industrial conditions on the boiler unit No. 2 of the type BKZ-220-100 (40) thermal power station PSC "DNIPROAZOT" are represented by the NOнд schedule in figure 5. The regime of moderate incomplete combustion of fuel was provided by maintaining the oxygen concentration values measured in the regime section of the flue after the reheater. His results are represented by the graph O2нд in fgure 5. Comparison of nitrogen oxide emission concentrations NOрк according to the regime map shows that in the regime of moderate incomplete combustion of fuel emissions of nitrogen oxides NO decrease by 30-40%. With a decrease of less than 1,04, there is an increase in the emission of carbon monoxide concentration (see the graph of CO in figure 4), comparable to a decrease in NO emissions. As can be seen from the graph of the dependence of the efficiency factor from the excess air factor (alpha), there is a reduction in efficiency. The boiler is slightly reduced. This regime can be attributed to the optimal both in energy efficiency and in reducing the negative impact on occupational safety in the premises of the thermal power station and on the environment of the surrounding atmosphere.

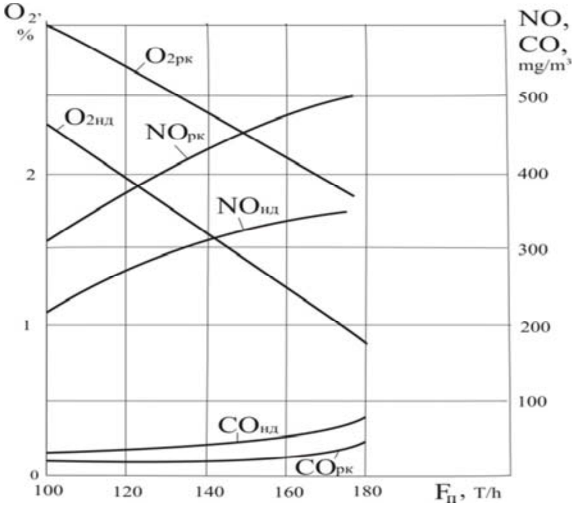

Fig.5. Dependence of the content of *NO*, *CO*, O_2 on the steam load of the boiler unit BKZ 220/100 (40)

The results of the above studies allowed the methods of signature mathematics to solve boundary value problems in the information spaces of technological processes to obtain a criterion for reducing the emissions of toxic gases into the surrounding atmosphere and for the energy-efficient operation of the boiler, expressed below by the equations (7) and (8):

$$K_{Эб1} = \frac{K_{O2} - 2{,}3 - (F_П - 100) \cdot 0{,}017}{2{,}33 - (F_П - 100) \cdot 0{,}017} \cdot 20^{0{,}5[1 - Sign(K_{O2} - 2{,}3 - (F_П - 100) \cdot 0{,}017]}, \quad (7)$$

$$K_{Эб2} = \frac{3{,}0 - (F_П - 100) \cdot 0{,}015 - K_{O2}}{2{,}5 - (F_П - 100) \cdot 0{,}015} \cdot 20^{0{,}5[1 - Sign(2{,}5 - (F_П - 100) \cdot 0{,}015 - K_{O2})]}, \quad (8)$$

where: $K_{Эб1}$ – airflow limitation factor at the upper limit of safety; $K_{Эб2}$ – airflow limitation factor for the lower safety margin; $F_П$ - steam consumption, t/h; K_{O2} – measured oxygen concentration, %.

Equations (7) and (8) form the control actions for the control station of boiler units "DIA", which support the information-controlled process of air-fuel ratio in the boundaries between the O_2*нд* and O_2*рк* diagrams in Figure 5.

The results of research and implementation of the proposed combustion method with controlled moderate incomplete combustion of fuel are confirmed by the conclusions of foreign works [9, 10, 11], in which such combustion technology is considered as a combined solution to the problems of improving the environmental safety and efficiency of the boiler.

2.4. A brief technical description of the station "DIA" for the management of steam boilers for the utilization of gases in coal mines

The "DIA" station is a multifunctional, maintainable, renewable, serviced product of long-term operation and industrial premises operated in a stationary environment. The complex of technical facilities of the "DIA" station is designed for round-the-clock continuous operation in the period of a given resource and interacts with the following equipment and units:

- power supply system;
- sensors, alarms, control and shut-off valves, pumps;
- a general network of techno-economic data exchange.

Station DIA provides control and monitoring of the boiler, namely:

- control of steam pressure in the steam receptacle by changing the supply of coal gas and mine methane;
- ensuring the safety of mine methane;
- control of the air ratio to the left / gas with correction for O2 and CO;
- control of air / gas ratio with O2 correction and CO;
- control of vacuum in the furnace on the left with correction for air consumption;
- control of rarefaction in the furnace on the right with correction for air consumption;
- control of the boiler drum level by supplying feed water;
- control of the boiler water salt content;
- monitoring of technological parameters;
- monitoring of emergency values of parameters and activation of emergency protection;

-provision of operation of process equipment without permanent presence of operating personnel in the area where equipment is located;

- transfer of information on technical and economic performance of the boiler to the information network. On the hierarchical principle, the "DIA" station belongs to the lower level, connected via the Profibus network with the existing upper level. The centralized control and management of boiler equipment is carried out from the operator room. The controller communicates with sensors and process parameter indicators through the input-output channels of communication devices with the object. Station "DIA" is designed for continuous (round-the-clock) work in real time with periodic inspection and routine maintenance during scheduled shutdown of the boiler.

Software and hardware provide operation of the "DIA" station in the following modes:

- boiler control during operation of the equipment in the modes stipulated by the technological regulations, including start-up, normal operation, normal and emergency stop;
- autonomously (without performing control functions) during commissioning, checking the characteristics of measuring channels, maintenance and repair of software and hardware.

Diagnostics of the "DIA" station is carried out by software in the prescribed modes of operation and provides verification of:

- the operability;
- the quality of the transformation and control functions;
- the communication channels between system components.

Diagnostic results are localization and fault location (hardware module, software).

OPERATING CONDITIONS

According to its resistance to climatic influences, the station corresponds to the performance of the temperate and cold climate allocation category 4.2 in accordance with State Standard 15150-69. The degree of protection against penetration of foreign bodies and water according to State Standard 14254-96: - IP40 - for cabinets. Operation is allowed under the following conditions: - under the influence of industrial radio interference provided in the "Union-wide norms of tolerated industrial disturbances" No 8-87-9-87, with constant and variable (frequency 50-60 Hz) magnetic fields of not more than 40 A/m; - at an ambient temperature of + 10° C to + 35° C and a humidity of not more than 80%, - at an atmospheric pressure of 84-106.7 kPa, - in the absence of conductive dust and vapors in the environment that cause corrosion of the materials used; - at the voltage of the supply network 220 (-33 V ... +22 V), frequency (50 ± 1) Hz.

RELIABILITY AND RESOURCE

Reliability indicators of the system are not lower than the following values: for control and protection functions - 30000 hours of failure time; for control functions - 20000 hours of operating time to failure; for information functions - 15000 hours of time between failures.

Average recovery time of the operational state of the Station "DIA" by replacing the faulty replacement unit, module or device from the spare parts inventory for not more than 1 hour, including the troubleshooting time. The average lifetime of the "DIA" station is not less than 10 years.

2.5. Substantiation of the choice of the software and hardware complex (SHC) for information energy-saving technology for extraction, transportation and utilization of coal mine methane gas

The selected SHC must ensure that all functions have been listed in the document "Methodological recommendations on the degassing procedure in the standard of Ukrainian organizations10.1 00174088.001 – 200413.

SHC should provide a convenient interface for monitoring and management, be completely open for development by the Customer's specialists, reliable, safe and financially accessible. The SHC must be suitable for constructing a design model for the design and simulation of the process. Considering a wide industrial approbation of the above requirements, we chose OpenSCADA SHC [12]. It is a system built on the principles of modularity, multi-platform and scalability, providing the ability to collect, archive and visualize information and issue control actions.

The OpenSCADA system (Fig.6) provides the following structural features:

• the creation of automated process control systems or telecontrol systems;

• construction of monitoring systems or management of a single technological process for production intensification; transportation and utilization of methane;

• creation of embedded systems (PLC runtime environment);

• construction of dynamic models and simulators; stages of technological processes;

• use on PC, servers and clusters: processing of information about its environment and equipment.

The main information monitoring functions in real time are:

1. Centralized control over the process flow, which ensures:

– periodic measurement of the values of process parameters;

– operative display of values of technological parameters;

– graphic and digital representation of the values of technological parameters and the interrelations between them on the mimics;

– graphical and digital display of the process history;

– graphical visualization of the history of the control loop;

– display the change in equipment status in the form of an event log;

– display the change in the state of the equipment in color on the mimics;

– visualization of the results of diagnostics of the equipment status on the operator panel screen;

detection, online display, logging in the archive and signaling of deviations in the values of process parameters and equipment status indicators from the established limits.

2. Diagnostics of equipment status:

– self-diagnosis of the microprocessor controller;

– diagnostics of the communication channel with the controller;

– diagnostics of measuring channels;

– diagnostics and control of the condition of equipment and fittings.

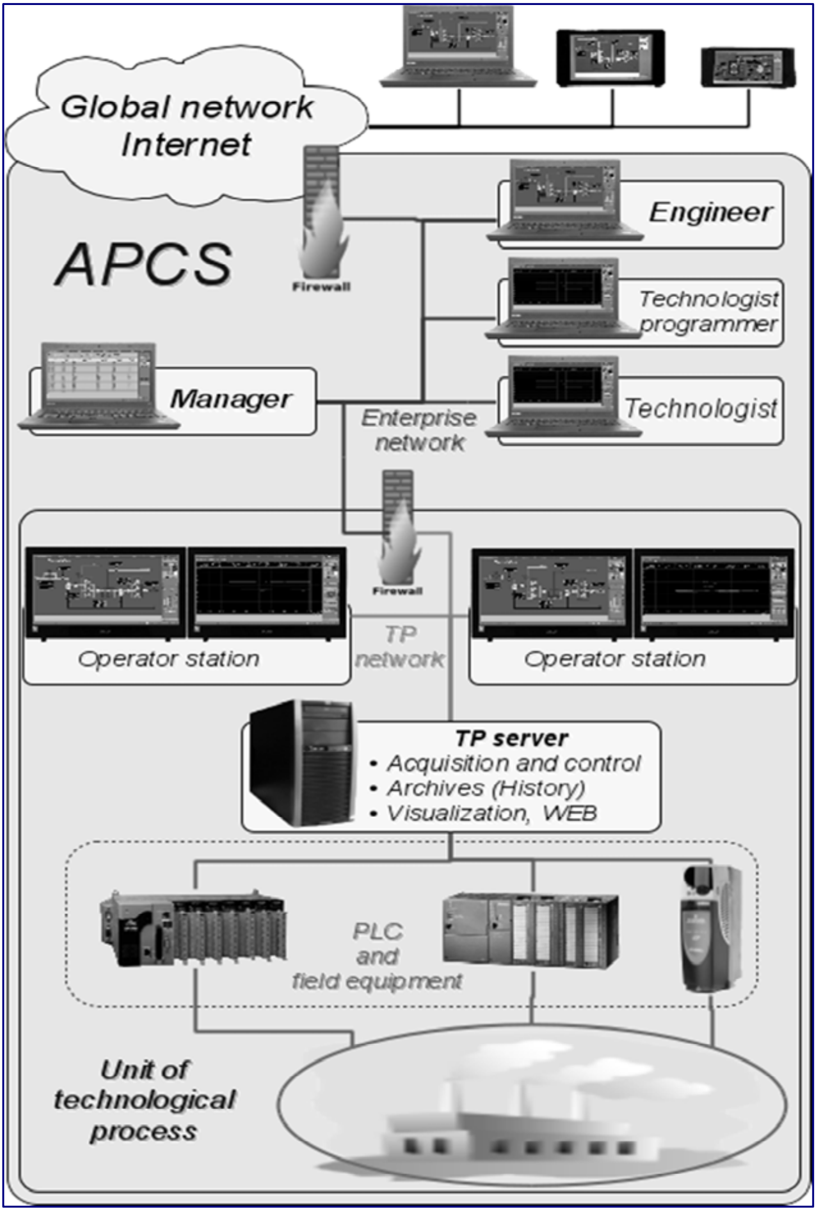

Fig. 6. Structurally-functional scheme of the OpenScada software

3. Registration and archiving of the process history:
- Instantaneous values of process parameters;
- changes in the state of the equipment (archive of events) - violations of the technological process.

Conclusions

1. The explosion safety criteria for methane-air mixtures are analytically justified and established for safe management of the excavation and degassing of isolated mine workings, from which the extraction of mine methane is extracted, as well as for the safety of its transportation and preparation at a gas-mixing station for utilization.

2. The structural and technological scheme of a single information-driven resource-saving technological process for extracting, transporting and utilizing the gases from a coal mine has been developed.

3. A criterion has been established for efficient control of the fuel-air ratio in the controlled moderate incompletely burned regime, which reduces emissions of toxic gases into the premises of the utilization station and into the surrounding atmosphere, as well as greenhouse gas emissions of methane and carbon dioxide.

4. Requirements are formulated for system-wide solutions and for the software and hardware complex information support for the information management of energy-saving technology for the coal mine gases extraction and utilization, and proposed for their implementation approved in the conditions of long-term industrial operation of the SHC based on OpenSCADA "DIA".

5. The closest prospect for introducing the information resource-saving technology of gaseous fuels curing, transportation and utilization presented in this work is the mines of the state enterprise "Toretskugol". To date, they have been developed, agreed and approved "Safety rules for control of the "DIA" station by boiler units of thermal power plant at utilization of gases of mines of State Enterprise "Toretskvugillya". The rules establish the requirements for designing, the complex of software and technical means, the manufacture, installation, adjustment, repair and operation of the measurement, control, signaling, information management and

emergency protection of boiler units of the thermal power plant at the utilization of the gases of the mines of the State Enterprise "Toretskvugillya ". In the projects of the "DIA" station, the sections should be provided: mathematical support, information support, system-wide solutions, software and technical support and organizational support for the commissioning of the station.

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IMPROVEMENT OF THE METHODS OF DESIGNING THE PERSONAL PROTECTIVE EQUIPMENT FOR THE WORKERS OF THE MINING INDUSTRY

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Abstract

The Research subject is the development of the theory and the methods of designing the personal protective equipment

The purpose of the monograph is the development of the methods of designing the personal protective equipment for the workers of the mining industry in order to increase their efficiency in terms of protection, reliability, and safety of use.

Methodology.The elements of system analysis and Risk-based approach as a means of solving the tasks are the basis of the research. During the development of the design of the personal protective equipment the basic provisions of the transformation method were used. The method of analysis of the failures and consequences is used in determining the risks of using the personal protective equipment.

Content. At the enterprises of the mining industry, the working conditions according to the indicators of the hazardous and harmful production factors, the severity and intensity of the labor process are harmful. The work in conditions of exceeding hygienic standards (3-rd class) is allowed only in case of using the personal protective equipment.The initial stage of determination of the needs of the workers inpersonal protective equipmentt should be the assessment of the risks of hazard to the workers` health. The indicator of the “risk” in use is proposed as an integral criterion for assessing the effectiveness of a particular type of

personal protective equipment. The main task of the process of designing the protective clothing depending on the certain working conditions is the choice of design and technological solutions in each design situation. Design and technological solutions for personal protective equipment protective in the foreseeable operating conditions must, above all, provide ergonomic characteristics, the maximum possible level of protection, guaranteed lifetime, without creating additional risks for use.

Conclusions. The practical solution of the complex tasks of creation of the sets of personal protective equipment is proposed to be implemented on the basis of the transformation method, which makes it possible to develop the design decisions depending on the list of harmful factors, their intensity and area of influence, and to limit the additional risks.

Introduction

Over the years of independence, Ukraine has made significant changes in the field of labor protection. The Law of Ukraine "On Approval of the State Social Program for Improving Safety, Occupational Health and Working Environment in 2014-2018" provides for the creation of organizational and legal conditions for the integrated solution of the problems of labor protection, for the increase of the effectiveness of the measures for the prevention of occupational injuries and occupational diseases, and for the implementation of state policy in this area at all levels of executive power using the mechanisms of social dialogue.

Creation of safe working conditions and realization of the best European and world practices of industrial safety in Ukraine is impossible without the design, manufacture and introduction of qualitatively new types of personal protective equipment (PPE) of the workers.

PPE refers to the means intended to eliminate or significantly minimize the complex impact of all available hazardous and harmful production factors (HHPF) on the worker in the workplace. Depending on the purpose, PPEs are divided into 12 classes, each of which consists of several dozens of kinds and types. In the absence of the universal unified classification, each type of PPE is classified according to the number of features: by protective properties; by appointment; by design execution; by model range, by the term of use.

As to the PPE, in order to perform their functions, they must, according to the purpose and degree of the protection, be clearly in line with the nature and level of the HHPF, and at the same time be acceptable from the physiological and ergonomic point of view, that is to provide the physical and technological compatibility of the individual PPE in the set of clothing, as well as with the object of protection, namely the worker.

The purpose of the monograph is the development of the methods of designing the personal protective equipment for the workers of the mining industry in order to increase their efficiency in terms of protection, reliability, and safety of use.

The elements of system analysis and mathematical modeling as a means of solving the tasks are the basis of the research. During the development of the design of the PPE the basic provisions of the transformation method were used. The method of analysis of the failures and consequences is used in determining the risks of using the PPE. The calculations and evaluations are carried out using analytical, statistical methods and expert analysis. Live experiments are used as a means of checking the adequacy of the proposed mathematical models and carried out using the modern measuring instruments in accordance with the methods given in the standards for the relevant PPE.

The practical significance of the obtained results is that theoretical generalizations and results of calculations have been used as a methodological basis for developing the approaches to designing the new high-performance types of PPE, the application of which will make it possible to increase the safety and productivity of miners and to reduce injuries and occupational diseases.

1. Working conditions of the miners in the coal mines

Nowadays in Ukraine the number of accidents and injuries, caused by them, is decreasing gradually, but at the same time there is negative trend – the growth of occupational diseases due to the further worsening of working conditions, aging and wearing of machines, mechanisms, buildings, facilities, untimely repairs and maintenance.

Most coal mines have outdated production assets with outdated equipment. Most of the mining equipment and machines are outdated and physically worn out. 58% of lifting machines, 53 % of main fans, 48% of compressors need replacement. More than 60 % of the mines are difficult to ventilate. About 40 % of air pipes and main drainage pipelines are corroded and give a lot of leaks. In addition, pipelines have a lowered caliber due to the accumulation of deposits of solid particles, contained in the mine waters. There is no reserve for lifting gears, main and balancing ropes, and headgear sheaves. Most of the mine shafts are in the disrepair conditions. The problem of degassing of mines and normalization of the working conditions of the miners is not been given due attention. When in other branches of the industry the aging of productive assets leads, in the main, to the reduction of the labour productivity, in mining industry it threatens the lives and health of thousands of miners.

At the enterprises of the mining industry, the working conditions according to the indicators of the HHPF, the severity and intensity of the labour process are harmful. The work in conditions of exceeding hygienic standards (3-rd class) is allowed only in case of using the PPE.

The HHPF in coal mines is caused by dust and gas pollution of the working zone, high noise and vibration, humidity and high speed of the air, which contributes to the occurrence of drafts. The absence of natural light leads to the insufficient level of lighting of the working area. In coal mines, workers are exposed to high temperatures and temperature fluctuations, with constant contact with water, oil, water with oil emulsions, drippings, sprays of mine water and dusty atmosphere. The atmosphere is saturated with aerosols containing fine particles of coal and rock dust. The working conditions are determined by large fluctuations of temperature from -20 °C to 50 °C at an increased speed of air up to 12 m/s and its humidity up to 80 %. The miner`s entire working time is in dusty air. The dust has fine particles of coal rocks with a concentration of up to 80 mg/m^3. Working conditions in a limited space cause work in uncomfortable working positions (lying down, with a stoop), friction on the sharp edges of coal and rock, which contributes to the risk of microtraumas of the skin of the body. During the working time there are significant static and dynamic loads – workers carry from one place to another the weight of up to 50 kg at a distance of up to 100 m.

The analysis of the incidence of diseases showed that about 60 % of all diseases are diseases of the upper respiratory airways. During the work in low-strength layers and water-supply mines, the levels of acute respiratory infections are 1.6 times, pharyngitis and angina – 1.7 times, and pneumoconiosis (dust disease) – 1.8 times higher than the average indicators in the industry. The growth rate of the disease is related to the temperature and air velocity, which in such workings is increasing significantly, and to the constant contact with water. This causes the increased requirements to the heat-protective and water-protective properties of the miner`s protective clothing.

When working on knees and elbows that have high sensitivity articulations, chronic bursitis develops as a result of the pressure and systematic damage. Such diseases of the workers, age 25 ... 40 years, lead to the long-term loss of labour capacity, in the elderly age contribute to the development of chronic diseases and the emergence of disability.

Long-term standing of the workers in dusty premises that contain silicon dioxide, coal dust, metal dust and their oxides, dust from mineral and organic fibers causes pneumoconiosis and promotes tuberculosis. Long-term work in premises with fibrous plant dust leads to emphysema-bronchitis. The diseases of the respiratory airways, lungs, digestive apparatus, osteochondrosis and radiculitis are the most common diseases among the miners.

In cases when workers during the working day undergo short-term or long-term impact of the HHPF (high temperature, dust, chemical solutions, radiation, etc.) and do not use PPE, accidents occur.

2. Characteristics of the tasks for creation, regulation and operation of personal protective equipment

The manufacture of PPE increases in Ukraine every year, the use of which helps to reduce the level of injuries and occupational diseases. The effectiveness of PPE application depends on the correctness of their choice and reliability during the operation and storage. The list of PPE is established by relevant norms or departmental documents, which are formed on a priori considerations, outdated experience and documentation, which does not provide for the use of mathematical justification.. PPE are given to the workers in accordance with the established rules and terms of wear, regardless of the form of ownership and industry. As of 2017, 82 normative legal acts on labor protection are in force, which define the norms of PPE. However, the lack of a unified methodological approach to ergonomics, protection and durability indicators, based on clear mathematical models and methods, creates significant difficulties for the PPE developer and the user.

The methods for the creation of protective equipment, proposed by the authors, are aimed at improving the design and construction methods, overcoming of the defects found and improving the comfort of use.

A large number of indicators, which are difficult to comprehend in full, should be considered when determining the parameters of PPE: sphere of application; protective properties; assortment range; indicators of quality, reliability, economy, comfort, and ergonomics. Quality indicators of PPE of general purpose are regulated by a large number of normative documents, special standards and intradepartmental documents.

Existing practice of determination of the quantitative parameters of materials and products provides for the conduction of experimental tests. In laboratory conditions, most of the parameters of characteristics of the materials and limit values (period of use, intervals of work and rest), as well as the level of harmfulness, microclimate parameters are determined the determined values ones, and are interpolated in the assumed linearity and invariability of the initial conditions, which does not correspond to the real conditions of use.

In order to improve the methods of choosing the parameters and modes of use of PPE it is best solution to have integral criteria that combine a number of parameters of materials and products, are characterized by analytical dependencies, and are formalized in mathematical models, which allows for simulation and optimization ocalculations.

The main regulatory document that defines the safety requirements, related to the peculiarities of the production, sale and use of PPE in the European Union is the Directive 89/686 / EEC, “Personal Protective Equipment” – PPE. That is to say, in the light of the requirements of this Directive, the relevant national Technical Regulation on PPE Safety is developed. Directive 89/686/EEC or, as it is also called, the PPE Directive is supplemented by Directives 93/68/EEC, 93/95/EEC and 96/58/EC. The main object of the PPE Directive is to guarantee the safety of the workers who use the PPE, and to guarantee the effectiveness of their core functions. The indicator of the "risk" in use is proposed as an integral criterion for assessing the effectiveness of a particular type of PPE. The initial stage of determination of the needs of the workers in PPE, as well as their choice, should be the assessment of the risks of hazard to the workers` health. Risk-based approach provides for the following sequence during the design and selection of PPE:

1 Assessment of the risks for the workers` health (risk assessment).

1.1 Identification of existing and possible dangers, HHPF that may affect the workers during their production activity (risk identification)

2 Quantitative risk assessments (risk analysis).

2.1 Determination of the probability of realization of dangers.

2.2 Determination of the severity of consequences of realization of dangers.

2.3 Risk assessment, i.e. evaluation of the level of the risk (risk evaluation).

3 Identification of measures and tools for the management of defined risks (risk treatment).

The main task of identification of potential dangers is the identification of the HHPF and the conditions for realization of their negative impact on the health and productivity of the workers during their work. The results of the risk assessment reflect the specific circumstances for the possible impact of the identified (each individual) HHPF on the worker.

When identifying indicators for assessing the hazardous conditions, the purpose of risk assessment and management is achieved – the determination of the baseline and the establishment of an acceptable level of residual risk. In order to justify the need of the workers in PPE, it is necessary to determine the actual levels of residual risks to the health of the workers, taking into account the implementation of all previous measures, aimed at reducing the risks at the workplace.

In order to determine the need for PPE, it is necessary to assess the risk factors that pose a threat to the health and workability of the workers at a specific workplace. The first step in assessment of the risks and identification of the workers` needs in PPE is the identification of the hazards. The list of possible dangers needs to be supplemented with those that arise in case of application of the means of protection of the body (protective clothing), respiratory organs, head, eyes, face, from falling from height, etc.

It is clear that different types of PPE should be used in sets. In order to justify the completeness of PPE, it is advisable to use the matrix of the relationship between the existing HHPF and the parts of the body: the head (skull, ears, eyes, respiratory organs, face, and the whole head), arms, legs, skin, trunk, pelvic area.

On this basis, there is an urgent issue of creation of the new sets of PPE that solve the following main tasks:

– compliance with outgoing requirements, based on the analysis of working conditions;
– provision of a basic level of protection and reliability indicators;
– not creating the additional threats to the worker's health;
– determination of the basic and provision of permissible residual levels of risk.

Such kind of approach provides for the possibility of taking into account a number of dominant criteria that are appropriate for the working conditions in the mining industry, and eliminating the possible negative factors by choosing and optimizing the design parameters and the corresponding manufacturing technology.

3. The concept of constructive and technological development of sets of personal protective equipment

In the coal industry, PPE are provided for the workers of every profession in accordance with the "Regulations on the Procedure for Provision of the Workers with the Special Clothing, Special Footwear and Other Means of Protection". The range of PPE for the workers of the coal industry is quite wide, and it is recommended to use about nine main kinds and thirty types of PPE:

– protective clothing: overalls, bib overalls, jackets, pants, suits, smock-frocks, topcoats, hoods, aprons, waistcoats;
– respiratory protection equipment: filtering respirators and self-rescuers;
– protective equipment for legs: knee-pads, boots, ankle boots, shoes;
– protective equipment for eyes: glasses;
– protective equipment for arms: mittens, gloves, elbow-pads, arm covers;
– protective equipment for face: masks, shields;
– protective equipment for head: hard hats, helmets, helmet liners;
– safety devices: safety belts, dielectric equipment;
– hearing protective equipment: silencer helmets, headphones.

All components of the set of PPE form a complete system, each part of which has a protective function. In general, set of PPE can provide a high level of protection against aggressive production environment and create comfort for its user.

3.1. Structural and technological development of protective clothing

Protective clothing means clothing used to replace the usual one or which is worn over it in the production environment in order to protect the worker from one or several types of danger. Protective clothing is the main type of PPE, which allows reducing the risk of occupational diseases and injuries to the skin of the miners significantly. Coal and rock dust that falls on the skin of the worker causes the pyoderma disease with the blockage of the sweat and sebaceous glands. Miners who work without relevant protective clothing in the conditions of deep mines and high temperatures have the average weighted indicator of skin dustiness equal to 0.116 g per 100 cm^2.

The workers involved in the repair of stall equipment, cutter-loader operators and electrical fitters have a high level of contamination of the skin by lubricants – from 0.01 to 0.043

mg/cm2. The greatest probabilities of contamination by lubricants have the workers engaged in the repair of stall equipment, utter-loader operators and electrical fitters at the mining sites. Arms and legs, hips, lower legs and abdomen areas are polluted the most intensity. As the research has found, in the first working days the concentration of oil has not exceed 0.001 ... 0.005 mg/cm2 of the surface of the protective clothing; after seven working shifts the oil concentration has increased to: 0.01 mg/cm2 on the abdomen, 0.043 mg/cm2 on the hips; 0.025 mg/cm2 on the lower legs.

The main task of the process of designing the protective clothing depending on the certain working conditions is the choice of design and technological solutions in each design situation. In accordance with the European Directives, design and technological solutions for protective clothing in the foreseeable operating conditions must, above all, provide ergonomic characteristics (that is, not to restrict the freedom of movement), the maximum possible level of protection, guaranteed lifetime, without creating additional risks for use.

Production suit means protective clothing that consist of a jacket (blouse) and trousers (bib overalls), aimed to protect the body, hands and legs from the declared HHPF (Fig. 1). Production suit can be used in a complete set with a waistcoat, a head-dress, an apron.

a b

Fig. 1. The show of the different types of suits for the protection of coalminers (a), steelworkers (b)

Upper shoulder protective clothing includes jackets, overalls, bib overalls, backplates, and waistcoats. Waist protective clothing includes trousers. Suits can be attached by alarm and lighting means, equipped with cooling elements and clamping and fastening devices, designed to pull out the worker.

Production jacket is a product with a cut or a zipper from the top to the down, which protects torso, arms and hips (partially) from various production factors. Jacket may be a part of the suit (Fig. 2).

Fig. 2. The show of the varieties of jackets

The shoulder protector is a product with inserted linen that has the shape of a pelerine, with ties, aimed to protect the shoulders, the upper part of the arms and the breast from mechanical damages (Fig. 3). The shoulder protectors must provide sufficient protection against mechanical damages in the foreseeable conditions of use, as well as have the damping properties sufficient to protect the upper part of the arms and breast from fractures and permeable injuries in case when some objects fall.

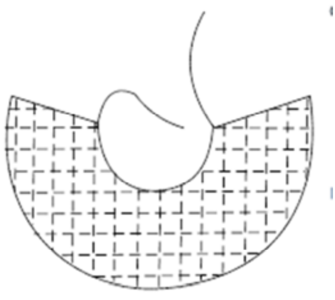


Fig. 3. The show of the shoulder protector

The backplate is a product with inserted linen that covers the back and shoulders and protects them from mechanical damages. The backplates must provide adequate protection from scratches, cuts, punctures in the foreseeable conditions of use, and have amortization properties sufficient to protect the back and shoulders from mechanical shocks that may result from falling or collision.

Production trousers mean a product that covers the lower part of the body and legs, aimed to protect these parts of the body against certain industrial factors. Trousers may be a part of the suit (Fig. 4).

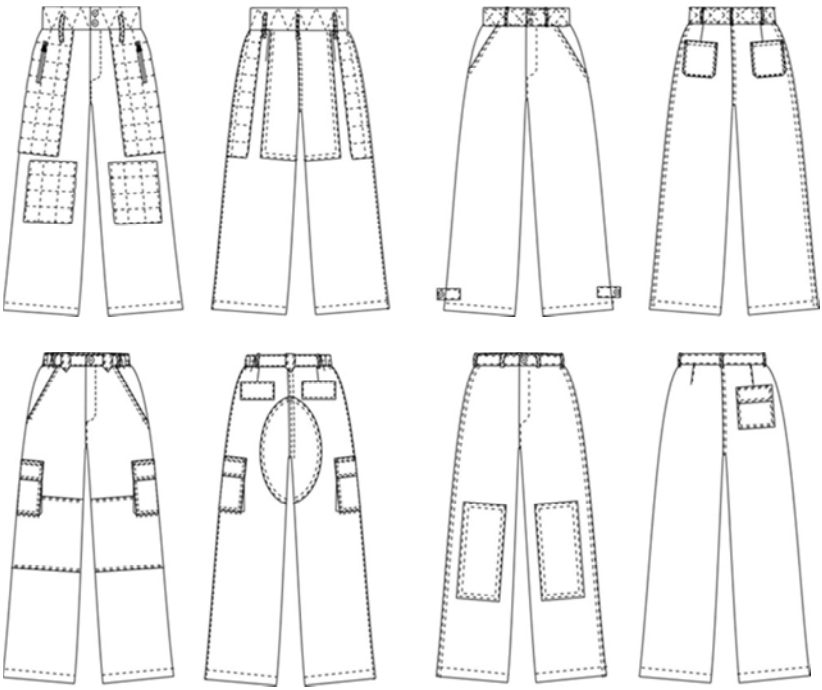


Fig. 4. The show of the varieties of trousers

Production bib overall is a product that combines shoulder clothes without sleeves and a collar, combined in one piece with waist clothing. Bib overall may cover the feet. Bib overall may be a part of the suit (Fig. 5).

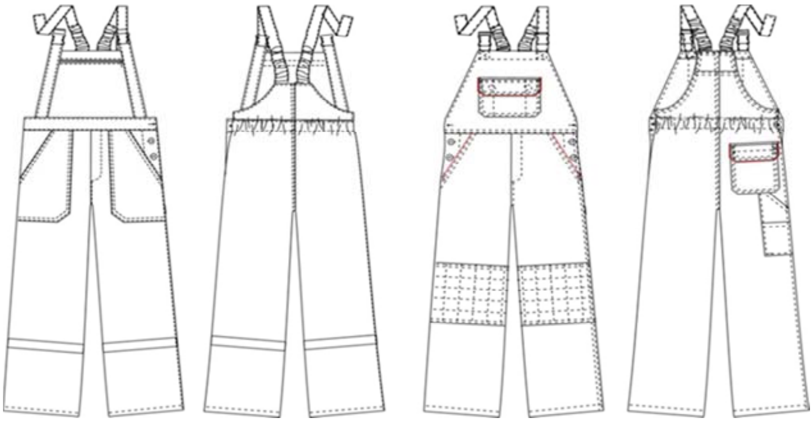


Fig. 5. The show of the varieties of bib overalls

It is noted that the choice of the model of protective depends on the user`s requirements and regulatory documents. Using the method of transformation, it is possible to provide sufficiently large number of requirements in terms of limited material resources. It is known that the term “transformation” means transfiguration, rotation, modification. The main idea of the design method, which is based on the principles of the theory of transformation, is the development of clothing of a new form or with other protective properties on the basis of limited amount of source elements through their sequential transformation. The theory of transformation describes the mechanism of connections between the elements of the transforming object. It is proposed to use the transformation method in the design of protective clothing, by which it is possible to modify the snarls of the clothes, details, clothing in general and its completeness, providing new protective functions.

3.2. Structural and technological development of the means for head protection

Equipment for protection of the head, legs, and arms, must be compatible with protective clothing and other PPE that should be used together, and with technical equipment.

Products for head protection are products that protect the head and neck. The products for protection of the head include helmets, hoods, helmet liners, hard hats liners. Helmets and hoods are the most effective. Helmet and hood are headdresses that tightly cover the head, neck and close the ears. Helmet and hood may have heat insulation with a visor, pelerine, equipped with a negotiating device, with hard hat (Fig. 6).

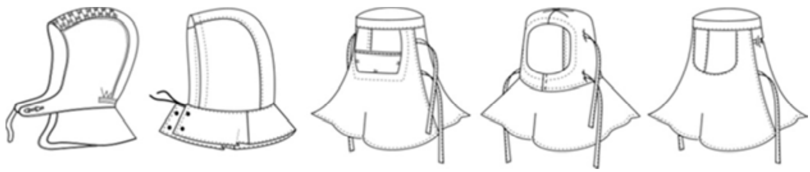


Fig. 6. The show of the varieties of helmets

The working conditions in the mining industry put forward a number of requirements to the PPE for head. For certain operating conditions, helmets (helmet liners) and hoods are manufactured:

– with cover plates (that differ by the shape, size, quantity, location and methods of connection with the products) or without them;

– with details that regulate the width of the product along the neck and head line (self-fabric carriers, strap details, shoulder straps, upturns, wrist braces, strings, elastic bands) or without them;

– with pelerines, visors, pockets, clacks for ears, straps (that differ by the shape, size, methods and means of connection with the products) or without them;

– with different layers of packages of materials (that differ by quantity, location, purpose, methods and means of connection with the products);

– with head points that differ by the quantity and size;

– with different fasteners (that differ by the quantity, location, methods of connection), namely: open or closed; central or displaced; zip fasteners, loops and buttons, textile fasteners, strings;

– with ventilation openings or without them;

– with different ways of connection with hard hats or without connection.

3.3. Structural and technological development of the means for arms and legs protection

Knee-pads are a product for protection of the legs in the knee area from mechanical injuries and damages (Fig. 7). Depending on the types of danger, different types of knee-pads are developed. For example, there are knee-pads for protection from general industrial contaminants and mechanical effects, from high temperatures, from vibration, and so on. Knee-pads must provide sufficient protection from scratches, cuts, punctures in the foreseeable conditions of use, and have amortization properties sufficient to protect the legs in the knee area, that have been hit by the objects of various kinds (that falling, stand proud from some place), in particular, from fractures and permeable damages.

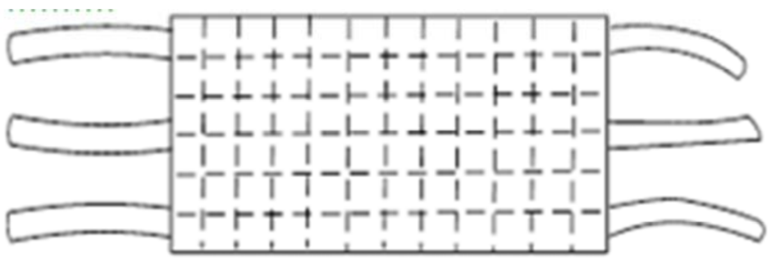


Fig. 7. The show of the knee-pads

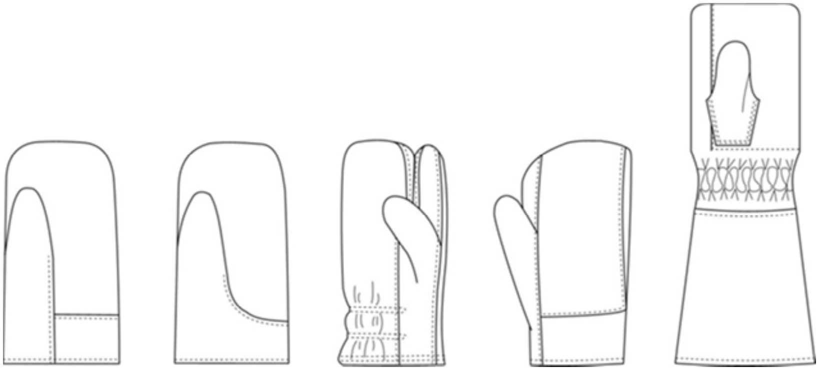
Products for arms protection are the products used to cover the arms and elbows. Such products for arms protection include mittens, gloves, cover mitts, arm covers, elbow-pads, wrist braces, hand covers. Mittens are PPE that protects the arm or its part from dangerous influences. Mittens (Fig. 8) can be made with cover plates and pads.

According to the design, there are several types of mittens:

– with set-in (Fig. 8, a), sewed on (Fig. 8, b), or full cut with the lover part of the garment finger guard;

– with finger guard, located on the side along the bend of the product (such mittens are used for both the right and the left hand) (Fig. 8, d);

– with two finger guards (for the big and pointer fingers) (Fig. 8, c);
– elongated, with cuff that stuck around the wrist, with hand covers and sewed on finger guard (Fig. 8, f).



a b c d f

Fig. 8. The show of the varieties of mittens

Gloves are a product with five finger guards, aimed to protect hands or part of the arm. Depending on the types of danger, there are different types of gloves and arm covers (Fig. 9).

a b c

Fig. 9. The show of the varieties of gloves with stitches (a), without stitches (b), arm covers (c)

Depending on the operating conditions, the following gloves and arm covers are manufactured:
- with layers of the packages of materials (different in number, location, purpose, methods and means of connection with the products);

- with cover plates on the palm and / or the back sides, and / or on finger guards of the product, etc. (varied in shape, size, number, location and methods of connection with the products) or without cover plates;
- with puffs, pockets, clacks, straps, etc. (various in forms, sizes, number, placement, methods and means of connection with products) or without them;
- with stitches or without them;
- with signal bands (different in placement, size and quantity) or without them;
- with various methods and means of connection with sleeves or without connection;
- with fasteners (different in number, location, means of connection) or without them;
- with details that regulate the width of the product along the wrists (strap details, upturns, wrist braces, strings, elastic bands) or without them;
- with different length of the finger guards;
- with cuffs of different lengths or without cuffs;
- with ventilation openings (different in type, number and location) or without them.

Cover mitt is a product, aimed to protect hands from burns while working in high temperature conditions.

Elbow-pads are a product, aimed to protect elbows from mechanical damages. Elbow-pads must provide sufficient protection from scratches, cuts, punctures in the foreseeable conditions of use, and have amortization properties sufficient to protect elbows from fractures and permeable damages.

Wrist braces and hand covers are products, aimed to protect wrists and palms from the mechanical injuries.

4. Risks that occur during the use of personal protective equipment

Available PPE create additional risks of injures and the occurrence of professionally predisposed diseases during their use. Protective clothing, intended for use during a work shift, has a high weigh, low air permeability and water vapor absorption, which greatly complicates the process of heat exchange between the external environment and the worker. There are additional inconveniences that arise because of the: occurrence of bugs during the use; decrease in the field of view compared with the usual one; deterioration of communications; complication of movements; violation of coordination of the movements, etc. Such conditions increase the worker's vulnerability to the surrounding harmful factors, increasing the probability of injures and delays during the work.

It is proposed to determine a quantitative level of hazard by estimating the magnitude of risk. The risk provides a quantitative picture of the possible consequences of the implementation of hazard, which enables to develop and implement the preventive measures, related to minimization of the occurrence of unwanted events or mitigation of their consequences. Risk assessment is required both at the PPE design stage and during its operation. In the first case, the reasons for the occurrence of unwanted events have been investigated and risks have been identified on the basis of preliminary information, obtained during the laboratory tests and experimental wearing in industrial conditions. Later, the complex of causes of failures and deviations from the planned parameters has been formed.

Failure Mode Effects Analysis (FMEA) has been selected for risk assessment. The method is based on statistical information, which records the errors in the functioning of the system. If adapt the main approaches of this method to the system of personal protection, the purpose is to assess the relative impact of the certain unwanted factors during the use of PPE and to introduce the additional measures, aimed to minimize the consequences and frequency of such events. Such method makes it possible to identify all the reasons for failures of PPE elements gradually, step by step. A failure mode is defined as the non-compliance to the requirements and parameters of the protective clothing, specified in the operating specifications. The failure of the PPE may occur in case of loss of declared protective properties, depressurization as a result of breaking, puncturing, cracking of the material, stitches, furniture under the influence of thermal, mechanical loads or electrical breakdown. Such failure can cause the partial or complete loss of protective properties and violations of a specified mode of operation, which may result in undesirable consequences (partial loss of workability due to the illness or injury). The assessment of the risks at the stage of designing the protective clothing has been carried out in order to determine the effectiveness of introduction of the additional corrective measures and means.

The concept of “risk” is introduced as a measure of the effectiveness of the use of certain types of PPE and their sets at different stages of the management of the security system. It is proposed to characterize the level of the risk from the PPE use with the help of the commonly accepted indicators in the theory (risk analysis). The analysis of the dangers carried out by the authors during the study of the PPE operating conditions at the mining enterprises showed that there are a number of sources of danger. The main reasons for the risks occurrence are the following factors:

1. Defection of protective properties of the materials. The causes of such damage are usually the wrong mode of operation, storage or cleaning.
2. Damage to the integrity of the products. The most common types of PPE destructions are caused by the insufficient level of physical and mechanical characteristics of materials and stitches of the product.
3. The occurrence of additional risks when using PPE due to the ergonomic factors such as: dynamic loads (limitation of movements of the hands, feet, head), static loads (increased weight of clothing), etc.

First of all, we define the basic risk that means the overall risk, which theoretically possible during the use of PPE.

$$R_i = \sum_{i=1}^{n} P_i \cdot D_i, \qquad (1)$$

where R_i– certain type of risk; P_i – probability of occurrence of *i*-th risk; D_i– consequences of occurrence of *i*-th risk.

After implementation of the planned activities, residual risk should be assessed, which is understood as the level of risk achieved through the introduction of additional measures. The level of residual risk is determined by the formula:

$$R_{зв} = \sum_{i=1}^{n} (P_i \cdot \nu_i) \cdot D_i \cdot W_i, \qquad (2)$$

where ν_i – weight coefficient for every *i*-th type of risk; W_i– possibility of introduction of additional measures to improve the design and enhance operational safety.

According to the existing practice, the risk should be within such limits: residual risk is equal to 10^{-6} per year; accepted risk - 10^{-4}; upper limit of individual risk is (1…5)10^{-5} per year.

Certain type of risk arises while k-events affect the worker simultaneously and each of such events has its probability of occurrence. Therefore, in the calculations, the probability of occurrence of i-th risk is proposed to be determined by the formula:

$$P_i = \prod_k P_k, \qquad (3)$$

where P_i– is the probability of the PPE refuse that will lead to the occurrence of *i*-th risk; $P_к$ – probability of simultaneous occurrence of the *k*-th event or phenomenon, which predetermines the formation and occurrence of certain consequences. Such events with respect to PPE includes the following probabilities: increased physical activity; formation of excessive harmful substances; significant changes of the temperature of external and internal thermal fields; air pollution by chemical, conductive, radioactive aerosols or by dust and other HHPF, which may adversely affect the worker.

The risk function is additive and the overall risk Rзв is determined by taking into account the n components that may arise during the use of the PPE:

$$R_{зв} = \sum_{i=1}^{n} (\prod_k P_k) \cdot \nu_i) \cdot D_i, \qquad (4)$$

The probability of the occurrence of risks for the worker's health will always be a consequence of PPE refuses; such kind of risk is associated with the receipt of injuries or diseases of different etiology (mainly multifactorial), which tend to increase during the increase of the worker's tenure in unfavorable working conditions or under the influence of the HHPF of the production environment, and labour process. For the risks associated with injuries or illness, quantitative estimates of the consequences are absent in most cases. Therefore, the paper assumes that the consequences of the i-th risk are equal to unit (Di = 1) and the value of the basic risk is determined by the probability of occurrence of undesirable events. Depending on the requirements put forward to the protective product in the design, we choose three components of the basic risk and f. (1) takes the form:

$$R_{3B} = P_3 \nu_3 + P_B \nu_B + P_E \nu_E, \qquad (5)$$

where P_3 – probability of loss of declared protective properties; P_B– level of reliability; P_E – probability of occurrence of additional dangers during the performance of the works due to the violation of ergonomic indicators; ν_3, ν_B, ν_E– weighed coefficients of each component.

The weight coefficients in f. (5) have different origins and, accordingly, are incommensurable, that is, it is impossible to distinguish the general standard for the comparison. Such indicators have different units of measure, their values are characterized by interval estimates and it is quite difficult to determine the functional relationships between them. Such complexities are possible to overcome at the first stage using the expert opinions and the ability of a specialist to make rational decisions upon condition of the impossibility of their complete formalization. In this case, determination of their relative importance with the experts' help facilitates the selection of the most significant risks and possible consequences of their occurrence. The method of processing the results of an expert survey was applied using the ranking method in conjunction with the method of successive comparisons. The expert assessment for determination of the weigh coefficients included the formation of a group of experts, expert interviews, peer review and analysis of the results. At the first stage, twenty six respondents were selected, including the specialists from labor protection enterprises, developers and manufacturers of PPE. For the weight coefficients obtained as the result of the processing of expert assessments, the following ratio is applied:

$$\nu_3 + \nu_B + \nu_E = 1 \qquad (6)$$

As a result of the research, the algorithm of determination of the basic risk during the creation of protective clothing of a certain purpose is developed:

1. The overall risk is considered as the sum of the risks, which are caused by the following factors: loss of protective properties; break of air-tightness of the materials and stitches; imperfection of ergonomic solutions in protective clothing designs.

5. Weight coefficients, which provide the degree of the influence of a separate indicator on the level of the overall risk, are determined, based on the results of the expert assessments, provided by the experts in regard to the importance of each component using the f (6).

6. The value of the overall risk for protective clothing is calculated using the f (5).

The proposed conceptual approach has sharply increased the requirements to the depth and the level of monitoring of the level of risk in the use of PPE at all stages – design, manufacturing, operation, utilization. Numerical values of the level of risk for each component make it possible to determine the sequence of the introduction of individual elements of transformation into the internal structure of protective products and to develop effective protective sets of PPE for performing of the work in certain hazardous working conditions.

Conclusions

1.The mining industry an important place in the Ukrainian industry. However, more than sixty percent of the miners work in dangerous and hazardous conditions. At the existing enterprises, due to the implementation of existing engineering and technical measures, it is impossible to avoid the influence of a complex of harmful factors on the workers. The use of personal protective equipment is an urgent need for every workplace.

2. The practical solution of the complex tasks of creation of the sets of personal protective equipment is proposed to be implemented on the basis of the transformation method, which makes it possible to develop the design decisions depending on the list of harmful factors, their intensity and area of influence, and to limit the additional risks

USING SMART DRONE
IN GEOLOGY AND MINE

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Abstract

This monograph gives a general insight into what SMART DRONE Technology is! How was it concepted? When did it begin to be used? What are its areas of use, and what can it do? Its use in geology and mining!

Smart DRONE is a recent, very advanced, very fast and highly efficient technology, which is the future of measurement technology in mining surveying. The information about DRONET has nothing to do with curiosity as future technology but about how mining companies benefit from their use.

The objectives of the Monograph is to: (1) Explain what is SMART DRONE Technology; (2) Define DRONE features; (3) Getting acquainted with DRONE types; (4) Understand how the DRONES work; (5) Give examples of DRONE's use in general; (6) Getting acquainted with the use of DRONES in Geology and Mining; (7) Know where to find out more about this technology.

1. INTRODUCTION

The name DRON has a connection to the word DRON which means "*male bee*" that works independently. DRONES (bees) are known for gathering in remote areas of congregation areas. Some studies have suggested that their magnetic orientation may be related to the fact that adult DRONETs contain cells that are rich in magnet[1] (Figure 1).

But in this Monograph we will not talk about DRON, male bee, biological DRONES, bees, but for a very advanced DRONI Technological. Although literally translated DRON means BEE, its technical meaning is INDEPENDENT AIR VEHICLE without pilot. The used term is UAV (*Unmanned Aerials Vehicle*).

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1 https://en.wikipedia.org/wiki/Drone_(bee)

An unmanned UAV vehicle, commonly known as DRON, but also known as other names, is a non-pilot onboard aircraft. Its flight can be independently controlled by a computer, by a command board used by a pilot on the ground, or by another aircraft. The Oxford Dictionary describes DRONES as "*Remote-less piloted aircraft or missile*".

Fig. 1: *Photo of one DRONE (male bee)*
[*Source*: https://en.wikipedia.org/wiki/DRONE_(bee)]

2. DRONES, A HISTORY OF FLIGHT ROBOTS

The history of DRONES began in the 1840s. An interesting example are the balloons used by the Austrian army in the attack on Venice in 1849 [2] (*Austrian army in an attack on Venice* (Figure 2) and by the Japanese during the bombing in Fugo in 1945 [3] (*the Japanese forces in the Fu-go bombings*) (Figure 3).

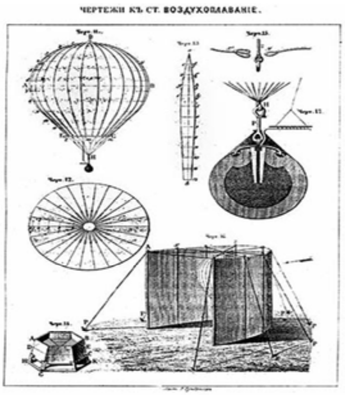


Fig. 2. *Bombing balone 1848*
[***Source***:http://www.ctie.monash.edu/hargrave/rpav_home.html#Beginnings]

Fig. 3. *Bombing balone*, 1945
[***Source***:http://www.wired.com/2010/05/0505 japanese-balloon-kills-oregon/

2 Austrian army in an attack on Venice
3 The Japanese forces in the Fu-go bombings

Public perception of most of DRONE's applications is still associated with their military use, but there are many who forget that one of the discovering fathers of the idea of *Remote Controlled Vehicle Vehicles* was genius scientist *Nicola Tesla*[4]. In 1915 he described a marine of unmanned aerial vehicles and in fact he was the first to register the patent of an unmanned pilot vehicle that he described as "*Teleautomation*", thus being the first to establish the principles of the today's DRONES[5] (Figures 4, 5).

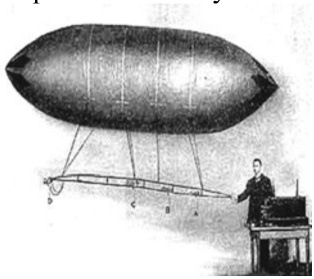


Fig. 4. *Nikola Tesla with his unmanned pilot vehicle 1900* [***Source***: http://www.ctie.monash.edu/hargrave/images/automaton_2.jpg]

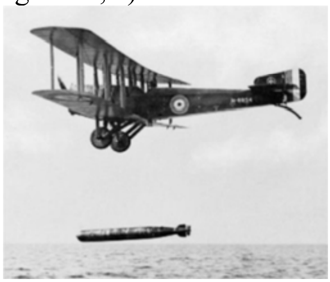


Fig. 5. *Air racket released by a bomber during first world war* [***Source***:https://en.wikipedia.org/wiki/Aerial_torpedo#/media/File:Sopwith_Cuckoo.jpg]

Interestingly, even before the Wright brothers told the aviation world the secrets of the "*new bird*" of controlled flight, there were others also who had tried to make DRONES (Figure 6).

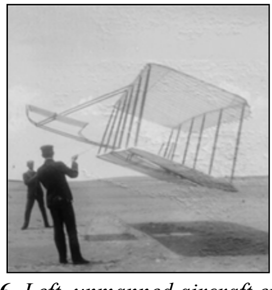
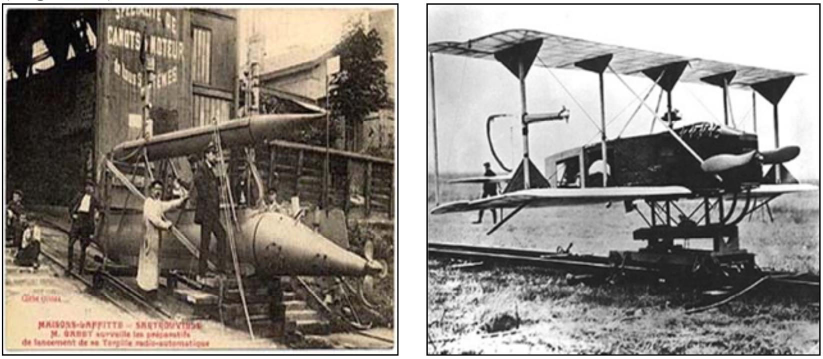


Fig. 6. *Left, unmanned aircraft erected in 1901 by Wilbu and Orville. Right, a non-motorized aircraft set up in1902 by Wilbur and Dan Tate.* [***Source****:* https://upload.wikimedia.org/wikipedia/commons/b/b2/WrightGlidersSideBySide.jpg]

4 Nicola Tesla

5 Foundation

DRONE's reuse began in the early 1900's, and they were originally focused on providing practical training objectives for military personnel. Their development continued during the First World War until *Dayton-Wright Airplane Company* invented an unmanned aerial rafting (FIGURE 7). The earliest attempt to produce an unmanned aircraft was made by A.M.Low's "*Areal Target*" in 1916[6]. A large number of remote controlled aircraft were produced during World War I, including a *Hewitt-Sperry* automatic aircraft (Figure 7).



(a) **(b)**

Fig. 7. (a) *Gabet and its radio automatic torpedo, 1909.*
[***Source***: http://www.ctie.monash.edu/hargrave/images/gabet_torpille03_350.jpg; http://www.ctie.monash.edu/hargrave/rpav_home.html#Teleautomata]
(b) *Hewitt-Sperry Automatic Airplane in 1918*
[***Source***: https://en.wikipedia.org/wiki/Hewitt-Sperry_Automatic_Airplane

The first pilot airborne vehicle was developed by a movie star passionate about aircraft models, *Reginald Denny* in 1935[7] (Figure 8).

OQ2 was the original model of a radio controlled radio, designed by *Walter Righter* (Figure 9) but the aircraft project was purchased by actor *Reginald Denny*. Radioplane OQ-2 is the UAV, or the first DRONE produced series in USA. During World War II, more than 9400 OQ3 were produced (the advanced OQ2 version).

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6 Nikola Tesla

7 Reginald Denny

(8)

(9)

Fig. 8. *Reginald Deny*
[***Source***: https://en.wikipedia.org/wiki/Reginald_Denny];

Fig. 9. *DRONE OQ-1*
[***Source***: https://en.wikipedia.org/wiki/Radioplane_OQ-2#/media/File:OQ-2A-Radioplane.jpg]

When *Ryan Firebee* was invented unmanned (DRONET) aircraft, they took first place in terms of use in World War II. Since then, the number of military DRONES used increased so fast that New York Time decided to refer to them as the *new paradigm for warfare*. During World War II this technology was used to train both anti-aircraft artillery and shooting missions. During this period, the Germans produced a series of unmanned aircraft types. In 1959, US air forces, due to the heavy losses of their pilots, began planning the use of unmanned aircraft. This plan was intensified after the collapse of the Soviet Union in 1960 and most of them were used during the Vietnam War.

In the years 1967-1970, *War of Attrition* made it necessary to include in unmanned planes detective aerial cameras. In 1973, in the war of Kuipur in Israel, DRONETs were used as a trap to attract opposing forces to unnecessary missile defence missiles. The Israeli plane *Tadiran Mastiff*, who flew for the first time in 1973, is thought to be the first unmanned military aircraft due to its *Data-Link* system and direct video broadcasts.

In the 20th century, military research brought the invention of many new technologies. Intelligence satellites enabled the GPS system and military seekers developed swapping protocols that are basic to the Internet. UAV (*Unmanned Aerial Vehicle*) fall into the same category.

Originally designed for intelligence purposes, their paramilitary and commercial development was often hidden from the public eye. The more technology advanced and the cost decreased, DRONE's daily civil use developed very fast. At the same time, the US military DRONE has triggered a wave of protests by the public because it has also created problems in breaching privacy.

3. CLASSIFICATION OF DRONES

DRONE classification is based on different criteria.

(3.1) ***According to the command mode*** DRONET are classified into two types: (1) Independent; (2) Commanded by means of the Control Panel.

(3.2) ***By way of engine fixing***, the DRONET is divided into: (1) DRONE with fixed motor at the wings; (2) Other Projects such as the MQ-8B Fire Scout, in the form of helicopters, etc.

(3.3) ***For purposes of use***: DRONETs are divided into 6 functional categories: (1) *Target and decoy* - providing ground and air artillery strikes simulating an aircraft or enemy missile; (2) *Discoveries* (Reconnaissance) - offering intelligence on the battlefield; (3) *Battleships* - providing striking skills in high-risk missions; (4) *Logistics* - specifically designed for logistic loads and operations; (5) *Research and development* - used for the further development of DRONE technology; (6) *Civil and commercial* - used for civil applications.

(3.4) ***Depending on the elevation and commanding distance***, the DRONETs are classified in 10 types as follows: (1) *Portable* hand held and uplifted up to 600m up to a distance of 2km; (2) *Short Distance* (Close) - 1,500m height and distance up to 10km; (3) *NATO type* - lift height up to 3,000m and command distance up to 50km; (4) *Tactics* - with a lift height of up to 5,500m and a distance of up to 160km; (5) *MALE* (medium altitude, long endurance) - with elevation height of up to 9,000m and command distance up to 200km; (6) *HALE* (high altitude, long endurance) - with elevation up to 9,100m and unlimited command distance; (7) *Hypersonic* - high speed with a lift height of up to 15,200m or suborbital lift, and distance up to 200km; (8) *Orbital* (Mach 25+); (9) *CIS* Lunar Earth-Moon transfer; (10) *CACGS* - Computer Assisted Carrier Guidance System for UAVs.

(3.5) ***According of the size***: DRONET divided into: (1) *Large* ones that will probably even one day transport passengers without the pilot's oversight on the plane; (2) *Normal*, size as those used in the army (); (3) *Small* ones, including those that are popular, called Kuopio. A Kuopio, also called a cadaveric or cadaveric helicopter, is a multi-rotor helicopter that is powered by four rotor motors. Figures 10 and 11 represent several types of Drones, military and civilians.

MQ-9 Reaper

Ryan Firebe

Schiebel S-100

Fig. 10. *Different Types Military Drones*

[***Source***: https://en.wikipedia.org/wiki/General_Atomics_MQ-9_Reaper; https://en.wikipedia.org/wiki/Schiebel_Camcopter_S-100]

(A)

(B)

(C)

Fig. 11. DIFFERENT *types of civil DRONES. (a) MicroDRONE md4-1000 used by DHL medical transport; (b) A DJI Phantom UAV economic purpose and areal photo; (c) AltiGator;*
[***Source***: http://payspacemagazine.com/wp-content/uploads/2015/08/image1-e1439206329671-690x446.jpg]

In Table 1, below is a comparison of small DRONES with large detection DRONES[8].

Table 1

Parrot AR. DRONE	Predator DRONE
• Weight less than 112 grams; • Size <than a pilot aircraft model. • Can be checked by eye from a pilot on the ground; • Price $ 300; • Width 60cm • Direct camcorder and video; • No License Required up to 120 m;	• Weight more than 1 ton; • Boeing 737 wing wings; • Checked by autopilot using a Pilot Linked Data Link. • The price 4 million $.

8 http://static1.1.sqspcdn.com/static/f/577812/9264817/1288873659433/NA-BI831C_DRONR_NS_20101102221101.jpg?token=0AP7B0B%2FPTacD8j6Evw1PqV7i9M%3D

(a) **(b)**

Fig. 12.(a) *Parrot AR.DRONE 2.0;* (b) *Predator DRONE*
[***Source***: http://www.flyingtoys.com/image/data/news/PE_Indoor_RED_3658.jpg;
[***Source***: http://www.successfulworkplace.org/wp-content/uploads/2014/01/Customs-Predator-DRONE.png]

4. AREAS OF USE OF DRONES

Scopes of DRONE usage are many. They are generally: (1) Military; (2) Civilians; (3) Fun. In a little more detail some of the uses of DRONES for Civilian purposes are given below.

(4.1) COMMERCIAL USE AND AIRCRAFT: Applications in this area include: Animal Monitoring; creating maps; Inspection of pipeline lines; Provision of housing, roads, etc.

(4.2) MEASURING, TOPOGRAPHY / GIS: DRUGS are widely used for air photography and LiDAR platforms. They allow us to make interesting pictures and videos from above! Thanks to Laser Scanners or Multi-Spectrum Cameras and MicroDRONE Technology we can accomplish many processes that with traditional technology would take a lot of time.

(4.3) MEASUREMENT SERVICE, TOPOGRAPHY / GIS: DRONES are widely used for aeral photos LiDAR platforms. They allow us to make interesting pictures and videos from above! Thanks to Laser Scanners or Multi-Spectrum Cameras and MicroDRONE Technology we can accomplish many processes that with traditional technology would take a lot of time.

(4.4) MOVIES: DRONE use in film making is very large, low cost and especially useful in rural areas with natural disabilities. So much has been added to DRONE's use in this area, for example, Los Angeles and New York have intervened to crash DRONES used to produce movies due to terrorist security.

(4.5) APPLICATION OF LAW AND PUBLIC SECURITY: Many police departments, including the Albanian Police, use DRONET for airborne surveys to protect the public and help coordinate security operations.

(4.6) GEOLOGY - MINES: DRONES can be used to search and carry out processes related to geology and mining. They help predict the location of mineral deposits, oil and gas production, and so on. DRONE technology provides realistic, measurable benefits in mining operations, reducing risk by increasing the speed and range of geo data collection.

(4.7) POSTING OF OBJECTS: Today, many companies are focusing on building standards to transport loads all over the world safely, quickly, environmentally friendly, and the lowest cost. Amazon has proposed that an airspace corridor over the cities and suburbs of the world, at a height of 60-120m, be free for fast moving DRONEVs capable of robotically flying almost without any human intervention. Amazon has undertaken to take its next ambitious step to deliver remote control packages within 30 minutes. It predicts that within the next 10 years hundreds and thousands of little DRIES will fly and the sky will become daunting. Meanwhile, another space between 120-150m will be announced as a banned airfield to act as a buffer between DRIVES and conventional conventional aircraft, mitigating fears of impact on flight and eliminating dangers.

(4.8) SUPERVISION: Now we can save everything from above! A drone micro DRON allows you to monitor everything without being seen or heard.

(4.9) SCIENTIFIC RESEARCH: With a DRON you can break barriers in fields that would hardly have been possible before. Let's take, for example, observe a volcanic eruption or documentation in archaeological excavations.

(4.10) AGRICULTURE-BUILDING-PROTECTION OF THE ENVIRON-MENT, ETC: DRONES encompasses a wide range of environmental prote-ction and conservation, animal world, glaciers analysis, soil erosion, etc.

5. RISKS AND PROTECTION FROM DRONES

As for military DRONES and civilian DRONES, public and environmental protection is a very controversial issue that has led to much controversy. Misuse of DRONES can bring unimaginable consequences.

The US military currently does not have a defence against low-level DRONE'S shocks, and therefore the Air Defence and Missile Defence Organization is working to re-dimension existing systems to protect American forces. Thus 2 German companies are developing 40 Kw Laser to harm DRONES. On the other hand, 3 UK companies have developed a system to track down and destroy the control mechanisms of small DRONES.

Bringing attention to a nearly 90-year-old pilot-pilot jet, Kuadopter's use is a step ahead. However, their use is a sensitive and complex topic related to many challenges related to technology, legislation, and social prejudices. For these reasons, England has established a number of organizations, including ASTREA, CAA or UAVS, which are designed to bring industry, regulations and civil partners together to unify future processes.

6. POTENTIAL OF DRONES IN THE FUTURE

The European Union says DRONE's market will absorb 10% of aviation in the next 10 years, even suggesting the main lines of their development. DRONES like low-cost aircraft are very intelligent but dangerous tools. They can watch and enter places where people cannot, or at least are not safe for them. Equipped with infrared cameras they can look a few times more than human eyes.

7. LEGISLATION FOR USE OF DRONES

Legislation for the production and use of DRONES is one of the challenging challenges facing the development of this technology. Different countries apply different rules, although efforts are currently being made to unify them.

US - Today in the US, to use a DRON for non-entertainment purposes under the Federal Aviation Administration (FAA), users must obtain an Authorization Certificate. In October 2015, the US Department of Transportation set up a Task Force that would set the requirements for DRONE registration for commercial purposes. In December 2015, FAA announced to Americans that they should register all DRONETs weighing over 250 grams by February 19, 2016.

To use a DRON in the US, the main conditions are: DRON Registration by 19 February 2016; To register on the portal you must be over 13 years old. If the owner is under 13 years old, the registration is done on behalf of the parents; Each registration will have its own Certificate and Registration Number at FFA; The registration cost is $ 5; The registration is valid for 3 years, and then needs to be renewed; Fines for non-registration range from $ 27,000 to $ 250,000 and imprisonment for up to 3 years. According to the Secretary of Transportation Anthony Fox and the Federal Aviation Administration (FFA) in the first 30 days of 2016, approximately 300,000 Drones owners are logged online, making a $ 5 payment.

DRONES used for hobbies or entertainment purposes have special rules such as: DRONS will only fly for entertainment purposes; DRON will operate in compliance with community safety rules; DRON cannot be heavier than 55 pounds otherwise it must be certified and tested in flight; When flying within the airport area about 3km away from the airport, the DRON operator must inform the control tower.

IRELAND: The Irish Aviation Authority has ruled that DRONES cannot fly without a special permit. The new rules of December 2015 include the registration of all DRONES weighing over 1kg.

SOUTH AFRICA: In 2014, the South African Civil Aviation Authority said it would overthrow any illegal DRONES flying in its airspace.

EUROPEAN UNION: After the use of DRON in the Serbia-Albania game, there was a great debate in the European Union about DRONE's rules of use. On December 7, 2015 EASA - the European Air Safety Agency, published its technical opinion on DRONET. This opinion includes 27 concrete proposals for a regulatory framework and to ensure low-risk operations of all unmanned aircraft.

This framework defines three categories, based on the perceived risk, as follows: (1) 'Open' Category (Low Risk): Safety is ensured through compliance with operational restrictions, product safety requirements, and a minimum set of operational rules ; (2) 'Specific Category' (Medium Risk): An Authorization by National Aviation

Authorities (NAA) is required. A manual of operations lists risk mitigation measures. (3) Category "Certified" (higher risk): Requirements are comparable to those for aviation transport of people. Licenses, training, etc. are approved by the authorities.

ALBANIA: The situation in Albania is unclear. From the current information there is no regulatory legal framework for this issue.

8. CONSTRUCTION AND FUNCTIONING OF DRONES

8.1. HOW DOES A DRONE WORKS?

The ordinary human illumination is that DRONES can work independently using computer programs provided for them. But DRONE'S operation is not just a task of computer software. Computer programs can help move and control DRON, but cannot provide the location and coordinates required by DRON.

There is a very systematic procedure of DRON'S operation. When DRON is sent on a mission, there are people who monitor it every second in order to eliminate any mistakes. DRONES without proper control are vulnerable and can be attacked by opponents. They may have the artificial intelligence of their direction, but always remember that Artificial Intelligence is just a series of binary codes that work together to form a command. Artificial intelligence has not yet reached the level when it can be used to anticipate attacks and threats. If you send a DRON on-site unsupervised, there are many chances that it will not return to the previous state.

8.2. CONTROL SYSTEM IN THE LAND

The operation of large, military DRONES, for example, is based on the signals transmitted from the base camp to a satellite repeater. Field DRONES are continuously monitored by the Control Centre at the base camp. The Control Centre is also called the Land Control Station (SKT), which makes sure DRON is always in front of our eyes. DRONE'S loss from our visual appearance can obstruct commands and this is always a situation that should be avoided (FIGURE 15a).

8.3. THE SATELIT COMMUNICATION LINE

There is a possibility that the Land Control Station may encounter difficulties during the mission, so there is always a spare place. This is accomplished by means of a satellite-based vehicle in the vicinity of any field control station that makes it safe and back-ups by supporting any program from the Satellite Control Station for satellite broadcasting in cases where direct communication loses. (Fig. 13b) Satellite Re-transmitter).

The satellite repeater has a very important role in any remote operation because DRONES sometimes faces technical difficulties in delivering field surveillance images. In this case, DRON transmits the images to the Satellite Transceiver. Subsequently, the Satellite Transmitter transmits the received data to the satellite uplink vehicle so that the Land Control Station can take the necessary actions. It takes about 1.2 seconds for an operator to reach DRON via a satellite connection. For each DRON is a special satellite used as a Satellite Re-transmitter. This reduces the error to zero and gives better results.

a) 

b) 

Fig. 13. (a) Land Control Station (SKT); (b) Satellite Re-transmitter

9. USE OF DRONES IN GEOLOGY AND MINING

9.1. GENERAL INFORMATION

Nowadays there is an increasing tendency to use DRONES in the field of Geology and Mining. There is nothing surprising if today a geologist does not carry a hammer and a shovel, but a technology that looks like a small airplane or helicopter. Already this technology is the future. Many geological and mining companies are equipped with DRONE that is used to search for minerals. Many other global mining companies are using multipurpose DRONES since the creation of exploration and mineral exploration maps and mining measurements. On the other hand, the information collected by DRONES is very valuable and can lead to better decisions.

According to new data in 2015 mines were focused on three main issues: (1) Improvement of security; (2) Asset Automation; (3) Management and control of mining operations. According to a study by IDC (International Data Corporation) 69% of global mining companies are seeking to carry out monitoring and mining operations remotely; 56% are seeking new methods of mineral exploitation; 29% are robotics; and 27% driven by DRONES.

DRONES have become essential in many major industries. One of DRONE's most promising applications is to assist in the extraction of raw materials, especially in the mining industry, in logistics, in equipment handling, in protective columns, pipeline inspection, etc. The reasons for their use are obvious. Expenses for the use of MicroDRONE are much smaller than for the use of aircraft or helicopters.

Applications that use Micro Drive are increasingly expanding into raw material quarrying. Vertical lifting cubicles are ideal for supplying spare parts, or to receive soil samples for deposit analysis.

9.2. EXPERIENCE OF DRONE'S USE IN MINE

DRONES are already used in mining and geology, almost in most countries such as USA, EUROPE, AUSTRALIA, AFRICA, JAPAN, etc. In POLONI, one of the companies offering orthophoto maps that is using DRONES is Photocopy - which is the leading provider of services in the Polish photogrammetric market and one of the areas where DRONES are being used are mining. In June 2014, Geoproject realized a photogrammetric air operation for the Obora mine near Lubin, Poland. The mission is realized by the Easy Map UAV produced by the Composer Trigger, which offers very good sensors and takes hundreds of photos per square kilometre. The processing used 19 photographic points and 7 checkpoints providing quadratic average errors in X and Y axes less than 3 cm and Z less than 13 cm. Such precision allows for the calculation of the volume of dumps and the volume of the wells, with acceptable accuracy. Changes in volume measurements showed a 1% difference between traditional methods. DENMARK: Similarly, in Denmark, the use of Drones for Oil Exploration and Detection has begun.

9.3. FIELDS OF DRONES USE IN GEOLOGY AND MINE

Unmanned aerial vehicles, otherwise known as UAV or DRONE are becoming very important for the mining sector. In recent years, these mini-helicopters have helped the industry find cheaper and safer ways to build deposit maps, searched and discovered for minerals, through remote control. The ability to monitor stocks, exploration of objects on the map, and tracking equipment makes DRONE use in the mining industry unlimited. The information about DRONES is not about curiosity as future technology but about how mining companies benefit from their use. The main areas of DRONE use in geology and mining are as follows:

9.3.1. SURFACE MINIER: The use of DRONES in surface mining is mainly focused on: (a) Surveys on quarries, stocks, surveys; (b) 3D modelling; (c) Transport of various equipment; (d) Quick Aid; (e) Monitoring of mass bursts; (f) Monitoring of Dams; (g) Transport of various equipment; (gj) Quick Aid; (h) Updating surfaces to optimize drilling design; (i) Identification of undeclared squads, etc.

9.3.2. WARNING MINES: In underground mining, DRONE'S use is focused on: (a) Measurement in mines; (b) 3D modelling; (c) Control of abandoned spaces; (d) Maneuvering of remote underground vehicles; (e) Positioning of underground vehicles.

9.3.3. MINERAL PROCESSING: (a) Monitoring of damp; Inspection of equipments of enrichment factories.

9.3.4. GEOLOGY: In geology, DRONE'S use is focused on: (a) exploration of minerals; (b) Construction of geological maps; (c) Model of geological deposits; (d) Planning of search and discovery guides; Coastal Coast Monitor; Monitoring slippage, etc.

9.3.5. NAFTA AND GAS: In the field of DRONES oil are mainly used in: Search-Finding; (b) Geophysics; (c) Monitoring of oil and gas transport lines; Surveillance of oil platforms in the sea and land.

9.3.6. TECHNICAL INSURANCE: In the field of technical security DRONET are used mainly in: (a) Control of hazardous areas; (b) Control of dangerous elements; (c) Inspection of machinery, oil rigs, oil exploration vessels; etc.

9.3.7. STORAGE OF OBJECTS: (a) Preservation and control of the mining area and equipment; etc.

9.3.8. ORGANIZATION AND PLANNING: In the field of organization and planning DRONES are mainly used in: (a) Mining inventory; (b) Statistical calculations; Decision-making.

9.4. TYPES OF DRONES USED IN MINING

There are many types of Drones used in mines. The most useful are: (1) KESPRY DRONES; (2) SENSE FLY; (3) eBee RTK; (4) MINEFLY; (5) Aibot X6 UAV; (6) Drone2GIS (Figure 14).

(1)

(2)

(3)

(4)

(5)

(6)

Fig. 14. *Types of Drones used in mine*
(1) KESPRY; (2) SenceFly; (3) eBee RTK; (4) MineFly; (5) Aibot X6 UAV; (6) Drone2Gis - [***Source***: (1) KESPRY.com; (2)**http://geospatialworld.net//Admincms/Filemanager/connectors/ashx/images/exom-senseFly.jpg**]; (3) **http://www.rdoequipment.com/images/uploads/page_images/1027/ebee_rtk.jpg**; (4) https://www.3dvisworld.com/features/feature-articles/10972-DRONET-for-scanning-and-mapping-underground-mines.html; (5)___ (6) http://drone2gis.com/us/

9.4.1. USE OF DRONES IN OPEN CAST MINE

As mentioned above, the use of DRONES in open cast mining is very widespread, ranging from Surveying to Surveillance to Mass Displays. Below we will look in a little more detail the use of DRONES in Measurements in Mines, and mainly in the survey and measurement of stocks.

The realization of topographic measurements in a open cast mine, quarry or private plot has many challenges. Placement of ground scanners and other surveying equipment in heavy equipment traffic, either slow down production or pose serious safety hazards to the measurement teams. Other safety aspects include health, hazards from steep areas, landslides, noise and dust. Conventional measurements take a lot of time, involve more than one person and can be very expensive. In addition to security concerns, logistics can also become difficult due to location.

9.4.2. USE OF DRONES IN stock's MEASURING

In the measurement of stocks, many types of Drones are used. Generally, through the use of DRONE, mining companies can automatically receive the perimeter, the volume of excavations and fillings, a special feature of the stock measurement application includes the ability to measure casing volumetric volumes, and automatic weight calculation based on the density of the material. KESPRY DRONES for example offer 2D images and 3D models that help with mining operations and their planning. (Figure 15).

Within a few hours and about 20 minutes DRON flight, data is available through the Cloud companion system. Using an iPad, the user can describe the stock zone or part of the operation that he wants to analyze. DRON flies automatically into the programmed path and captures high resolution data. Further, the WIFI Unit sends the data to CLOUD where they are processed, and where the profiles are built. Instead of days of field observations and measurements, or maybe weeks of airborne surveys, a 3-dimensional model has been built and made available within a few hours.

Automation allows these DRONES to avoid many accidents due to human errors. There is no directional lever; it rises automatically; Runs up to the right elevation and flies in the pre-defined flight plan itself, and returns back to the launch site itself. It also allows the operator to avoid the process of intensive work in the stock picking process, to carry out GPS measurements, thus improving the operator's life insurance. "

Fig. 15. *Using Kespry Drone to measure and calculate stock volume*
[***Source***: http://www.KESPRY.com/wp-content/uploads/wapiti_yard.jpg]

The data collected by DRONES can be used to generate 3D high score renders, allowing a safe way to assess career conditions. (FIG. 32)

It is very useful for DRON to build 3D models before starting work and then day after day to see how much material has moved.

9.5. USE OF DRONES IN UNDERGROUND MINES

As mentioned above, the use of DRONES in underground mines starts from markings to the positioning of underground vehicles. A special and very interesting case is the use of DRONES for mapping underground mining.

9.5.1. SCANNING AND MAPPING OF UNDERGROUNG MINES

The new DRON technologies have reached a wide range of uses, resulting in increased need to improve security and maximize the efficiency of underground mining operations. Keeping in mind the dangers and challenges that commonly encounter during mining operations, DRON's new technology is on its way to replacing methods of intensive measurement, inspection and mapping. This is emerging as a new trend in the mining industry to capture 3D space data in difficult areas in underground mining in order to reduce the risk and increase security. Large-scale 3D mapping and underground environments, such as floors, slates, protective columns, space utilization, etc. will now become lighter and more cost-effective. This marks a new era for underground mines in the future.

9.5.2. USE OF DRONES IN DANGEROUS ZONES

With the great dangers posed by underground mines, inhumane support has always been appreciated. While robots seem to have found their place in mines, the DRONES have not yet found their balance. This period of uncertainty will not last for much longer. As reported by MINE Magazine, DRON has successfully mapped a coal mine in Germany, marking the first unmanned pilot mapping mission in an underground environment. Apart from the fact that DRON faced uncontrolled underground winds, he also faced obstacles such as clouds of dust, endangered walls, barriers and uneven terrain. But the most interesting part is the fact that DRON accomplished this entire mission independently (self) by choosing his own way, overcoming the predestined path. This technology will undoubtedly be decisive in mines, when DRONES will provide real-time mapping services that can be made to hazardous underground environments.

9.5.3. SECURITY AND OPERATING EFFICIENCY

In terms of operational safety and efficiency, underground mines have unique challenges, some of which can be handled with technology, such as 3D laser map and DRONES. So, of course, we have a push towards building such systems that are quite powerful for difficult underground mining environments as well as cost-effective. The future is promising, key techno-logies exist and can be used to build high efficiency products. For example, Clickmox Solution has developed a 3D mapping system based on the Simultaneous Localization and Mapping (SLAM) algorithm, which can be installed on DRONE and vehicles. This system is capable of building real-time 3D maps without the need for a GPS signal.

All of these technologies are closely related to the so-called Internet of Things or IOT, which envisages a highly connected and highly intelligent system where each individual component communicates with other components and makes decisions based on the need of that moment. 3D scanning and mapping that facilitate positioning and automatic collision avoidance are important parts of such a system. It is anticipated that based on IOT, it will be possible for miners to use autonomous and DRONE vehicles to increase safety and productivity.

9.5.4. MINEFLY - THE FUTURE OF SUBSTANTIARY HARTOGRAPHY

The scanning and cartographic system DRON'S potential is based on 3D laser surface scanners, without greatly limiting flight time. Cartography and scanning are just two applications of such a system. This technology can be used to avoid obstacles and positioning in areas where no GPS coverage is available. MineFly, developed by Clickmox Solutions, is a system that allows anyone to use this technology in various applications (FIGURE 16). Other existing solutions are very expensive. Based on 3D laser scanning, precision auxiliary engines, monitoring unit, on-board computer, and a convenient program, this system yields the result which cost many times cheaper than other homologous methods.

Fig. 16. *The DRON MineFly with cartography and 3D scanning ability*

[*Source*: https://www.3dvisworld.com/features/feature-articles/10972-DRONET-for-scanning-and-mapping-underground-mines.html]

MineFly has been developed by Clickmox Solutions to overcome most of the challenges in underground mining operations where physical presence can be difficult, expensive, and can endanger high risks. This is a complete system consisting of a lightweight 3D scanner and is capable of recording very accurate spatial measurements. With 30 mm accuracy up to 20 m distances, the 3D scanner on MineFly is ready to scan any underground work. Possible uses of such a system in underground mines are 3D scanning of large surfaces, 3D mapping, convergence monitoring, inspection, markup measurements, 3D profiling, CAD construction and vehicle positioning.

9.5.5. MINING SURVEY AND 3D SCANING

Underground mining operations are needed to create bases and mapping networks. Such networks are created through Point Cloud created by a laser scanner, which is a time-consuming and expensive process. These issues make it unworkable to perform repetitive scans to update maps because the sub-conditions change. A scanning and measurement system based on DRONES solves these problems by allowing the work team to perform frequent, repetitive scans quickly and efficiently. This data acquisition method also provides increased security, which is an extremely important aspect of groundwater mining operations (Figure 17.A).

9.5.6. MONITORING OF CONVERGENCE

The changes that affect the sidewalls of galleries are a very important part of underground mining construction. Due to ongoing mining operations and seismic activity, galleries and columns begin to expand and converge, which can lead to localized collapse, endangering people's lives and equipment. Consequently, monitoring convergence is an extremely important task that is routinely carried out in underground mines.

Typically, this is accomplished by so-called extensometers (an instrument to measure deformation of pressurized materials) which are high precision gauges. The section of galleries in different positions is measured and recorded by means of the extensometers. Measurements are repeated and compared to determine if convergence is underway. This technique, though producing very accurate results, has the negative side that produces results only at the points where the measurements are made and requires intensive work. 3D laser scanning provides a much more effective measurement of extensometric measurements, allowing quick measurements that cover the whole area and not just individual points. 3D scanners developed by Clickmox Solutions can be installed on underground machines and DRONES to facilitate such measurements.

9.5.7. VEHICLE POSITIONING

Because mineral resources have diminished, exploration of the largest depths of the Earth's crust has begun. Many mines operating around the world have gone deeper than 2.5km. Such depths pose major challenges to operations, security and logistics. This has encouraged the design and development of independent vehicles. One problem in such developments is information on the location of vehicles, which is indispensable for any autonomous operation. In this case the challenge lies in the fact that there is no GPS signal in the underground. MineFly scanners solve this challenge by implementing the SLAM algorithm. (Simultaneous Localization And Mapping). As DRON flies, it automatically creates a 3D map of the area with dynamic location information. The same system can be installed on any vehicle in the underground mines. In fact, Clickmox Solution has produced such a device (Figure 17).

(a) (b) (c)

Fig. 17. *(a) 3D map of a gallery realized by a 3D Clickmox Scanner; (b) 3D Scanners Systems; (c) Real-time positioning of cars in car galleries using 3D scanners;*
[*Source:* https://www.3dvisworld.com/features/feature-articles/10972-DRONET-for-scanning-and-mapping-underground-mines.html**]**

10.1. USE OF DRONES IN GEOLOGY

As in mines and geology, the use of DRONES has begun to be present. Currently their use is focused on: (a) exploration of minerals; (b) Construction of geological maps; (c) Modelling of geological deposits; (d) Planning of search and discovery guides; (e) Calculation of Reserves; (f) Geophysical models, etc.

The question is how DRON can find minerals? The technology used in this case is multi-spectral imaging. By DRON it can be seen outside the red, green and blue electromagnetic spectrum. It is known that various mineral bodies have different spectral properties, so by computer processing we have the potential to configure what kind of bodies they are. Also by means of the DRONES can be calculated the reserves of the deposits, etc.

Although small and limited in their capacity, the use of Micro DRONES in geological studies is great, while their size and simplicity makes them very valuable even in educational environments. Air polls, maps, and monitoring can be done in real time and the collected data can be downloaded quickly at the end of each flight. DRONES provide access to areas that are difficult to reach, or are dangerous, such as abysses, rocky outcrops, or unstable volcanic areas.

An example of using Microdones is the use of Mount Yasur Volcano in 2014. In this case DRON has flown directly over the active volcano through gases and dust by making recordings and photos. The observations from the crater lips showed 3 flashes of lava, while in fact from the DRON video and video production 6 active lava flashed. Likewise during the flight DRON also took gas and dust camps for further analysis.

10.2. USE OF DRONES IN OIL AND GAS

The constant high price and the dramatic shortage of fossil resources require more and more new technology. In this case, the use of DRONES in the field of research, detection, production, and processing and oil transportation is playing a decisive role. Their applications start from exploration and preparation of production to monitoring and maintenance of pipelines in remote areas.

Multispectral DRONE data allows drawing conclusions about the soil conditions of the mining areas. On the other hand, inspection of oil pipelines is very important. After drilling, DRONES is used to monitor transport systems very economically and effectively. For the visual inspection of a DRON pipeline section it only needs a few hours - meanwhile for the same process with traditional methods of work it will take about a week. Sensitive sensors on the flying robot give the status of the pipeline. Possible leakages are immediately verified and as a consequence the repair becomes faster. The MicroDRONE moves independently to a previously programmed inspection path. In the event of anomalies or checkpoints they can easily be placed manually.

Geologists in Norway are using flying DRONES cameras to search for oil. So far geologists have used seismology at the bottom of the ocean to look for oil. They are now using DRONES to create maps of new oil reserves. Using laser scanners, infrared sensors and digital cameras, researchers create virtual models. Each small pixel of an image can store information about minerals and rocks. The use of DRONES in oil exploration is similar to the techniques used in Switzerland and Germany to search for minerals (Figure 18).

Fig. 18.

Oil and Gas used DRON
[***Source***: https://www.microdrones.com]

10.3. DRONES on labour safety

As in many other industries, monitoring of infrastructure, workplace and technical security are priorities of a geological and mining company. The widespread expansion of a surface mine, for example, justifies a study of air - and thus the use of DRONES is a cost-effective option. Anyone involved in geological-mining operations knows that employee safety is of paramount importance. By allowing the observer to collect accurate spatial data from above, DRON can reduce the risk and minimize time and staff spent on the field. DRONES deliver very good results in: Control of hazardous areas; Control of dangerous elements; Tower Tunnel Control; Well drilling; Massive outbreaks. Providing first aid, in the case of accidents, breakdowns, major fires, mass explosions where ground and air conditions are difficult for rescue teams, are another DRONES contribution.

10.4. OBJECTS SECURITY

Providing workplace, equipment and environment is another area of DRONE application in the field of Geology and Mining.

10.5. ORGANIZATION AND PLANNING

It may seem strange, but DRONETs are very important in the field of organization and planning in geology and mining. Specifically, data collected by DRONES are successfully used in: Minie-rays inventory; Statistical calculations; Short term and long term planning and organization of works; Wells management; Communication of daily and weekly plans; Optimization of surface roads; Damage Assessment and Storm Control; Dams Management, etc. In the case of long term planning DRONES is used to calculate for: Road, damp and well design; Geotechnics; Surface stability monitoring; Mining control in unbroken areas; Prepare maps in areas that cannot be violated.

10.5. LOGISTICAL ASSISTANCE FROM AIR

Mining areas usually lie on large surfaces, over several square miles. This means long journeys and road transport often takes great time. DRONES or flying robots are much faster and, besides monitoring and inspection, are also ideal for quick dispensing of spare parts, tools and lubricants needed for maintenance or repair work. DRONES can help not only as a first responder, but also as a means of transport for urgent medical cases. They can even monitor the condition of the car and automatically react to different events.

11. ADVANTAGES OF THE USE OF DRONES IN MINING INDUSTRY

The use of DRONES in the mining industry has obvious advantages.

(1) LOW COST: One of the biggest benefits of using DRONES is the cost. The cost of renting a helicopter, for example, can cost $ 2,000 per hour, and the cost of sending a couple of operatives with a DRON system is less than $ 200 per hour, "says Mike Hutt runs UAV projects for the US Geological Survey According to British Columbia Accuas Inc., DRONES will eventually become the future of mining operations (Scott McTavish, Accuas president).

(2) TIME AND SPEED OF OPERATIONS: DRONES act quickly and efficiently. DRONI can greatly reduce the time spent in collecting accurate data. Many of the Drone SenseFly customers show that work that was done in a few weeks with traditional methods now takes place for several days.

(3) ACURACY: Constructing maps with Drones provides a fast and affordable alternative to each measurement. With raster data from above - in the form of georeferenced digital imaging images, with resolution up to 1.5 inches (0.6 inches) per pixel - can gather millions of data from points within a short flight. The GNSS / RTK receiver systems are capable of effectively receiving data corrections transmitted from a base station or via VRS to achieve accuracy in coordinates X, Y, Z up to a minimum of 3 cm (1.2 in) without the need for strengths in the field. Likewise Drone MineFly for 3D laser scanning reaches a precision up to 30mm at a distance of up to 20m.

(4) QUANTITY OF DATA: Drones can accumulate millions of data in a very short time. By making data collection so simple, we can focus our energy more on using and analyzing data than to work out to gather them. The huge and growing amount of physical data that is collected means an increase in the time spent in the office for processing and using this data. This waste of time has now diminished many times by the use of DRON on the ground.

(5) SAFETY GROWTH IN THE FIELD: Spending less time on the ground means increased personnel safety, minimizing the risk when measurements are made in such places as mines, unstable slopes and transport routes. With DRON's side, simply select the landing and landing position and work is unsafe.

Investments in DRONES: Investing in DRONES is growing. Australia's mining industry spends roughly $ 3.7 billion a year on research and development and the ability to operate more effectively in remote regions.

The Cost of DRONES: DRON'S prices range from $ 100 to $ 30,000, depending on model, flight time, and size (Table 2).

CONCLUSIONS

(1) Smart Technology DRONE is occupying an ever-increasing place in economic and social life, as it is considered as the technology of the future in many areas.
(2) Smart DRONE technology also equipped with laser scanning capabilities is operating in various industries, including geology and mining.
(3) Some countries have specific legislation on DRONE's use.
(4) Albania has begun to use very little, mainly for entertainment and police purposes;

RECOMMENDATIONS

(1) It is recommended to introduce DRONE Technology in all areas of its use in the field of Mining, Geology, Oil and Gas;
(2) It is recommended to include the DRONE technologies in the curriculum of the University studies;
(3) It is recommended to prepare and implement the necessary legislation and rule of safety for DRONES using.

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APPLICATION OF THE COMBINED VIBRATION ANALYSIS METHOD OF THE OVERHEAD TRAVELING CRANE TO PREVENT NEGATIVE IMPACT ON THE STRUCTURE AND PERSONNEL

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Abstract

The subject of the study is the application of the combined method of vibration analysis for the study of dynamic phenomena in the elements of the overhead traveling crane structure that affect both the durability and reliability of structural elements and the health and efficiency of maintenance personnel.

Research methodology - simulation of cargo lifting dynamics using Matlab Simulink and SolidWorks software, using combined calculations in which the system response generated from the solved system of differential equations in Matlab Simulink was used to excite the crane support structure during the FEM simulation in SolidWorks.

The goal is to identify the vulnerabilities in the construction of overhead traveling cranes, by examining the dynamic phenomena in the structure and the effect of vibration on the safety of the crane's operation, on health, and the capacity of the operating personnel.

Conclusion of the study. The proposed method allows more accurately and less costly predict the response of the crane structure to various dynamic effects, particularly lifting and lowering the load. The presented models of FEM and rigid masses can become the basis for studies based on an integrated approach that integrates the dynamic model with the CE model. The influence of the action of various vibration frequencies on the machinist's body of the overhead traveling crane is analyzed.

1. Introduction

The tense industrial environment in modern social production has led to the fact that the number of patients with vibration disease is 45% of the total number of workers with occupational diseases [1]. Therefore, it is important to have an integrated approach to this problem by combining compliance with the relevant requirements for occupational safety and health, the implementation of organizational and technical measures and reasoned scientific research.

Vibration is a mechanical vibration of solids, parts of machines, machines, equipment - with a frequency range of 0.01 - 500 Hz. It has a negative, harmful effect on the health of the worker, namely, changing the functions of organs, leading to concussion, deformation or rupture of tissues and cells of individual organs, violates the anatomical location of human organs (shifts their position, reduces their size). As a result of the overhead traveling crane, vibration damages the equipment, destroys the design, and also leads to disruption of the vital functions of workers.

Each of the structural components of the overhead traveling crane carries out its own forced oscillations, which are characterized by the corresponding values of amplitude, vibration velocity, vibration acceleration, frequency, initial phase [2]. Vibration oscillations are superimposed on each other at the work of mechanisms and transmitted to the body of the overhead traveling crane, as a result of which the latter carries out oscillations, which are actually vibration.

Depending on the method of transmitting vibration to the human body and the nature of its action on the body, vibration is divided into three types:

- general, which is transmitted through the supporting surface to the whole body while working;
- local, which acts on separate parts of the body, first of all limbs and is transferred to the hands of the worker of the overhead traveling crane,
- as well as the combined effect of general and local vibration with different or identical frequencies.

The general vibration of prolonged action on the worker of the overhead traveling crane at high levels of vibration velocity can become the cause of a working occupational disease - a vibration disease.

Depending on the origin of the source, the total vibration is subdivided into:

- a transport vehicle operating on a person in a moving vehicle;
- transport-technological, which is transferred to the overhead traveling crane driver;
- technological, transmitted through the floor, foundations or work platforms for workplaces without vibration sources

By time characteristics general and local vibrations are divided into:

- constant for which the value of vibration acceleration or vibration velocity varies less than twice (less than 6 dB) per working shift;
- not permanent, for which the above-mentioned parameters of vibration vary by at least twice (6 dB and more) for a working shift.

In turn, non-constant vibrations are divided into:

- oscillating, whose levels continuously change over time; interrupted when contact with vibration during operation is interrupted, and the length of the intervals during which the contact takes place is more than 1 s;
- Pulse, consisting of one or more vibration effects (e.g, strikes) each less than 1 s in length, with a frequency of less than 5.6 Hz.

The nature and extent of the impact of vibration on the human body depends not only on the type and parameters, but also on the direction of its action. Therefore, the vibration is divided depending on the axes of the orthogonal coordinate system X, Y, Z, along which it operates. Human body is particularly sensitive to vertical total vibration (along the Z axis) when some fluctuations are passed from head to toe.

The action of vibration on the body of a crane driver:

- Whether the vibration is short-lived, the worker gets tired prematurely, his productivity is decreasing.
- Whether the vibration is prolonged, it results in violations of the central and autonomic nervous systems, the gastrointestinal tract, the vestibular and musculoskeletal system, the cardiovascular system and genital organs, disorders of the sensitivity of the skin, peripheral blood flow, muscle and bone deformities, vascular

spasm , changes in joints, which leads to a restriction of their mobility.

In this regard, it is very important at the design stage of the machines to make constructive solutions that prevent the occurrence of vibrations, which can negatively affect both the machine itself and the driver.

Analysis of the design using the finite element method (FEM), provides information on the state of stress, shape and frequency of its own oscillations or deformations induced by external load, own mass of construction and cargo. However, by this method it is difficult to simulate dynamic processes, such as transients induced by a moving trolley or lifting cargo. Therefore, when analyzing processes occurring at the combined effect of motion and vibration, the simulation of FEM becomes insufficient [3]. In this case, for the description of physical processes, it is advisable to use a combined model that includes the interconnection of two or more models. In this connection, the modeling of cargo lifting dynamics was carried out using Matlab Simulink and SolidWorks software. To perform these simulations it was necessary to apply combined calculations in which the system response generated from the solved system of differential equations in Matlab Simulink, was used to excite the crane bearing structure during the FEM simulation in SolidWorks. The study of the dynamics of cranes on a model with rigid masses and elastic-dissipative elements limited by several degrees of freedom does not give complete information about the vibration of the entire structure [4, 5, 6]. However, using the combined method, after applying the calculated vibrations to the FEM model, one can observe the behavior of the entire structure with an accuracy to its individual elements.

The article offers a simple phenomenological model of a lifting mechanism. The use of such a model is caused by the preliminary character of the studies of the combined approach in the binding of phenomenological models and FE models.

2. Object of study

The article presents a combined vibration analysis of a two-girder overhead crane used at the enterprises of the Kryvyi Rih basin with a payload of 10 tons and a span of 28.6 meters (Fig. 1). The construction of the crane is described in detail in [7].

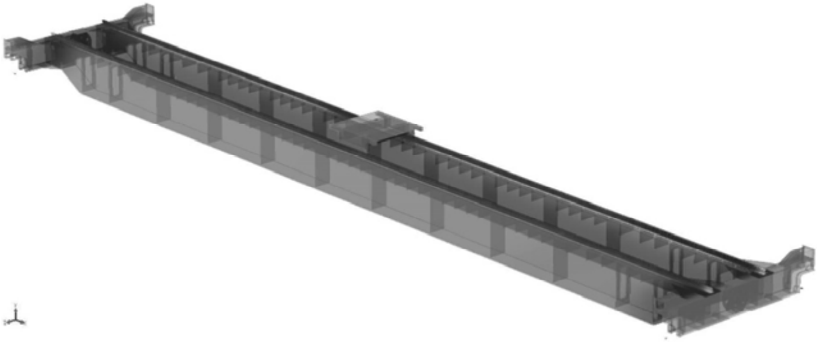

Fig. 1. Geometrical model of the investigated overhead crane

Tables 1, 2 and 3 show the general characteristics of the crane, prepared on the basis of technical documentation

Table 1

Main characteristics of overhead crane

Characteristics	Unit. measurements	Value
Truck		
lifting capacity net of main lift	t	10
height of main lift	m	10
multiplicity of main hoist		3
Geometrical parameters of the crane		
base	m	4,9
span	m	28,6
Installation dimensions of the crane and trolley		
base of trolley	m	1,485
bogie track	m	2,0
Crane height from rail head level	м	2,31

Table 2

The speed of the crane mechanisms

Mechanism	Rated speed, m/s (m/min)
The main upsurge	0,345 (20,7)
Crane movements	1,67 (100,2)
Moving the trolley	0,51 (30,4)

Table 3

Masses of the main elements of the crane

Element	Units	Value
Total mass of the crane	т.	39,89
Main girder weight	т.	14,48
Weight of the end beam	т.	1,99
Trolley weight	т.	4,97

Reliable results of studies of the stress state, displacements and natural oscillation frequency can be achieved if the materials with characteristics corresponding to real materials, real loads and when assigning the correct fastenings of the crane elements are used in the model.

Considering the fact that most of the elements of the crane construction are made of structural steel Cт3, for sheet elements of the main and end beams, steel Cт3 is also adopted as the material with the following characteristics (Table 4):

The investigated crane has a box-like structure in which one dimension (wall thickness) is substantially lower than the others. This type of construction has the lowest overall bridge height and high fatigue strength.

Table 4

Material data used in calculations for sheet products

Property	Marking	Value
Young modulus	E	210×10^3 H/mm^2
Poisson's coefficient	ν	0,28
Bulk density	ρ	7800 kg/m^3
Limit of fluidity	σ	235 H/mm^2

3. Combining methods of modeling and measuring of vibration

At present, various modifications of hybrid modeling are used to analyze dynamic systems [8]. Investigation of the properties of the object in the dynamic model allows to reveal the dynamic interactions of the crane elements such as the effect of the characteristics of the drives on the crane structure, the driver's cabin and other components.

There are two models are used in the offered method: the FEM model of the object and the phenomenological model. The FEM model is used to determine the model parameters given. This model provides information on static deviations and stresses. The FEM model makes it possible to carry out an experiment that allows modeling the behavior of structural elements under the influence of processes occurring during lifting of a cargo, movement of a crane and a freight trolley. This allows to determine the stress, deflection or acceleration during the lifting of the load.

The generated data is superimposed in the form of a kinematic impact on the crane model constructed using the FEM. Therefore, the main task of the study is to construct a phenomenological model of the object, which allows modeling the processes occurring in it. The generated data is superimposed in the form of a kinematic impact on the crane model constructed using the FEM. This allows to get more complete information about the vibration of all elements of the structure and the ability to predict the values of the selected parameters at any of its points. A fast Fourier transform allows one to obtain an amplitude-frequency spectrum representing the frequencies of oscillations that are components of this spectrum. This allows us to identify resonance zones and determine the dynamic effects on metal construction [8, 9].

4. Phenomenological and FEM model crane

In order to apply the combined method, it is necessary to create two models - FEM and a phenomenological model of overhead traveling crane.

Features of the FEM model creation.

Since the thickness of the walls is much smaller than other dimensions, the FEM was constructed as consisting predominantly of sheet elements.

The model is represented by 261 components, 38 of which are unique (they are the basis for cloning of other components).

In static studies, the load on the crane consists of loads from the crane's own weight and load from the weight of the load. The weight of the solid model of the crane is 21, 32 tons. The weight of the crane, the prototype of the passport, is 39, 89 tons. The difference in the weight of the model and the prototype arises from the lack of mechanisms, galleries, repair area and other elements in the model. The difference in weight between the prototype and the model was compensated by the introduction of a distributed mass into the model: 1227 kg on the base plate of the freight trolley and 8152 kg on the outer side sheets of the main beams.

The weight of the cargo is taken into account by applying a distance load of 10,000 kg to the trolley. Remote load is located at a distance of 5 m. below the place of rigid attachment. The scheme for applying loads is shown in Fig. 2

Fig. 2. Scheme of application of external loads

As global, the type of contact "Connected" with the parameter "Incompatible grid" is accepted. To ensure the reliability of calculations, the relationship between the elements of the crane structure and the rails is realized by introducing virtual planes into the solid model, the geometry of which is responsible for the geometry of the location of the contact between the wheels and the rails. To model the contact between the rail and the crane wheel, the plane has the form of a triangle with a vertex located at the point of contact of the rails and wheels. The contact line between the wheel of the freight trolley and the rail is modeled by a plane having the shape of a rectangle. Between the corresponding planes and the fixing points of the axle-boxes, there is a connection of the type "rigid connection".

To obtain a reliable result, it is important to provide the necessary degrees of freedom in the place where the crane is supported on rails.

In [10] - [12], the crane wheels have a fixed fastening, in our view, incorrect. When the crane operates, due to the elastic compliance of its body, the wheel's plane can rotate around the point of contact (PC) with the rail as with respect to the vertical axis running from the PC, and relative to the horizontal axis that passes through the PC along the rail axis. In this regard, for the solid-state model wheel fixing are applied that provide the necessary degrees of freedom. The planes simulating the contact between the crane wheels and the rail, have "Reference geometry" attachments with free rotation around the corresponding attachment points. For one of the drive wheels, is established travel restriction along all axes, for the other - along the rail and in the vertical plane, for the non-drive wheels - the restriction of movement is only laid in the vertical plane (Fig. 3).

Taking into account the topic of the article, studies were made of the natural frequencies of the crane. Frequency analysis - allows to calculate the natural frequencies of the structure and the corresponding modes of vibration. When the natural frequencies coincide with the frequencies of the external forces, a resonance phenomenon arises in the structure, which often leads to the premature destruction of the most resonating elements. To prevent resonance, the design must have its own frequencies located at a lower frequency than the exciting forces.

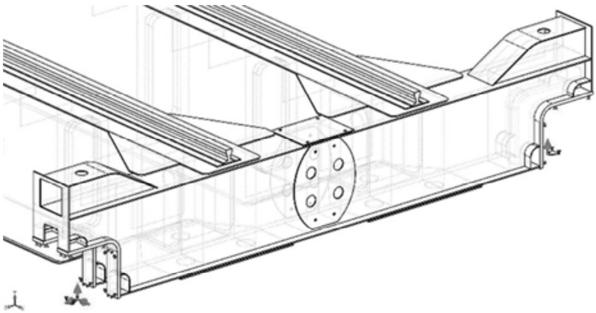

Fig. 3. Scheme of fasteners of the model

To calculate the natural oscillations, the FFEPlus decision program was used. The first 6 frequencies of the natural vibrations of the crane without load and with the load were calculated. The results of the research are given in Section 5.

Features of creating a phenomenological model.

A dynamic model of a crane with a lifting mechanism is shown in Fig. 4.

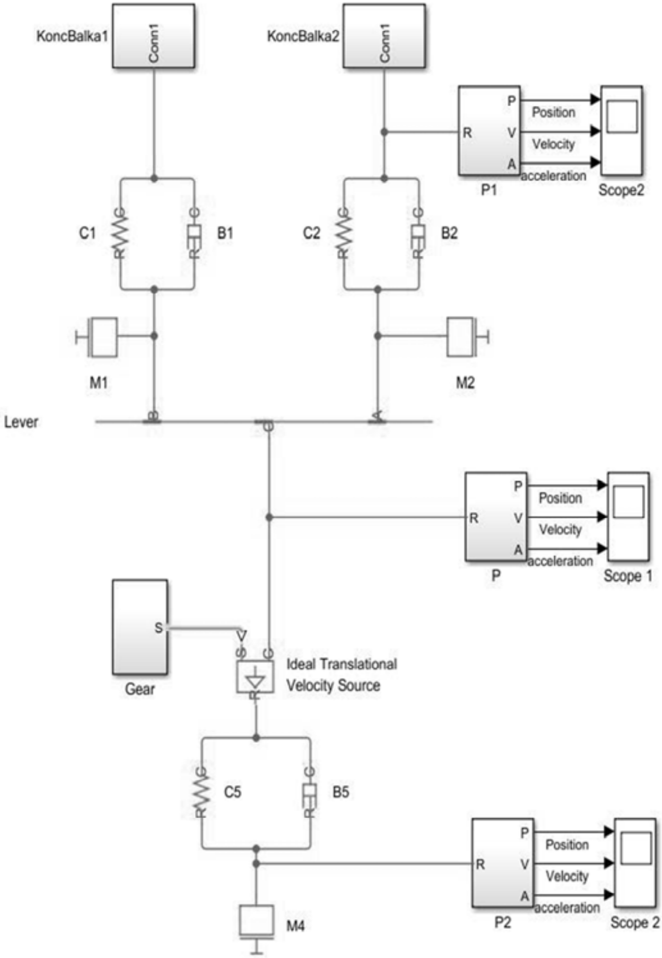

Fig. 4. Simplified phenomenological model of the crane

This model includes such elements of construction as the main and end girders (Fig. 5) and the load - lifting mechanism (Fig. 6), the rope and the cargo.

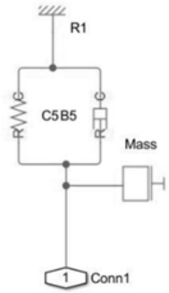

Fig. 5. Simplified model of the end beam

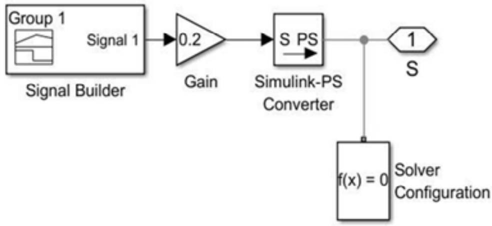

Fig. 6. Drive model

Based on the concept of generalized coordinates and the phenomenological model shown in Fig. 3-5, the equations of motion can be written as the Lagrange equations of the second type [13, 14]:

$$\frac{d}{dt}\left(\frac{\partial E_k}{\partial \dot{q}_j}\right)-\frac{\partial E_k}{\partial q_j}+\frac{\partial E_p}{\partial q_j}+\frac{\partial E_R}{\partial q_j}=F_j, j=1,2,...,n$$

where: t - time, q_j - generalized displacement, $\dot{q}_j$ - generalized velocity, n - number of degrees of freedom, F_j - generalized force, E_k - kinetic energy, E_p - potential energy, E_R - energy dissipation function.

This approach allows to obtain differential equations of motion in the form of kinetic energy of the system:

$$E_k=\frac{1}{2}m_1\dot{q}_1^2+\frac{1}{2}m_2\dot{q}_2^2+\frac{1}{2}m_3\dot{q}_3^2+\frac{1}{2}m_4\dot{q}_4^2+\frac{1}{2}J_4\dot{\varphi}_4^2$$

wherein: m_1 - reduced mass of main girder, m_2 - mass of end beams, m_3 - mass of load, m_4 - mass of the rope drum, J_4 - mass moment of inertia of the rope drum, $\dot{q}_1$, $\dot{q}_2$, $\dot{q}_3$, $\dot{q}_4$, $\dot{\varphi}_4$ - generalized velocity.
The potential energy of the system:

$$E_p=\frac{1}{2}c_3\left(q_1+q_2-q_3\right)^2+\frac{1}{2}c_2q_2^2+\frac{1}{2}c_1q_1^2+\frac{1}{2}c_L\left(-q_4-q_3+\frac{R_4\varphi_4}{i_W}\right)^2$$

where: c_3 - stiffness coefficient of the cable drum axle, c_1 - stiffness coefficient of main girder, c_2 - stiffness coefficient of end beams, c_L -

stiffness coefficient of wire rope, R_4 - radius of the cable drum, i_w - gear ratio of pulley blocks, q_1, q_2, q_3, q_4, φ_3 - generalized displacements, and the energy dissipation function:

$$E_R = \frac{1}{2} b_1 \dot{q}_1^2 + \frac{1}{2} b_2 \dot{q}_2^2 + \frac{1}{2} b_L \left(-q_3 - q_4 + \frac{R_4 \dot{\varphi}_4}{i_W} \right)^2$$

where: b_1 - girder damping ratio, b_2 - end beams damping ratio, b_L - wire rope damping ratio.

The coefficient of rigidity of the rope, determined by the relation (5), and its value depends on the length of the rope:

$$c_L = \left(n_{lin} \cdot A_l E_l\right)\left(L_0 - R_3 \varphi_3\right)^{-1}$$
$$E_l = (0,4 \div 0.65) E_s$$

where: n_{lin} - number of bands of wire rope, L_0 - initial length of the rope, E_l - modulus of elasticity, A_l - metallic cross sectional area of wire rope, E_s - Young modulus for steel.

The coefficient of rope dissipation was found from the known stiffness coefficient [15]

$$b_L = \frac{\delta \sqrt{c_k \cdot m_{гр}}}{\pi}$$

where, $\delta = 0,23$ is the logarithmic decrement of the oscillations, is determined from the oscillograms from [16], c_k - rigidity of the rope, m_{rp} - mass of the end load.

The rigidity of girders and end beams was determined from the expression [17]

$$C = \frac{3 \cdot E_S \cdot J_x \cdot (a + l)}{a^2 \cdot l^2}$$

where, E_S - modulus of elasticity, Jx - moment of inertia of the section, a - distance from the point where the force is applied to the left support, l - distance from the point of application of force to the right support

In the Matlab-Simulink environment, the dynamic model was formulated as a flowchart. Table 5 shows the physical parameters describing the considered vibration model, which are evaluated on the basis of the technical documentation of overhead traveling crane and own research.

Table 5

Physical parameters of the system under study

No.	Symbol	Value	Unit	No.	Symbol	Value	Unit
1	m_1	7315	[kg]	13	b_3	4.00E + 02	N/(m/s)
2	m_2	7315		14	b_4	4.00E + 02	N/(m/s)
3	m_3	1284	[kg]	15	b_5	1.17E + 06	N/(m/s)
4	m_4	1000	[kg]	16	L_0	10	[m]
5	J_3	16.15	[$kg \cdot m^2$]	17	A_l	5,53E -05	[m^2]
6th	c_1	7.99E + 06	[N/m]	18	E_s	2.10E + 11	[Pa]
7th	c_2	7.99E + 06	[N/m]	19	E_l	1.16E + 11	[Pa]
8	c_3	1.40E + 08	[N/m]	20	g	9.81	[m/s^2]
9	c_4	1.40E + 08	[N/m]	21	V_p	0.345	[m/s]
10	c_5	1.18E + 09	[N/m]	22	n_{lin}	4	[-]
11	b_1	4.00E + 04	N/(m/s)	23	J_{x1}	1,973E + 10	mm^4
12	b_2	4.00E + 04	N/(m/s)	24	J_{x2}	1.46E + 09	mm^4

Due to the fact that the studies cited in the article are preliminary, the signal of influence the load is accepted to a very fast engine start, without a control system. The shape of the control signal is shown in Fig. 7.

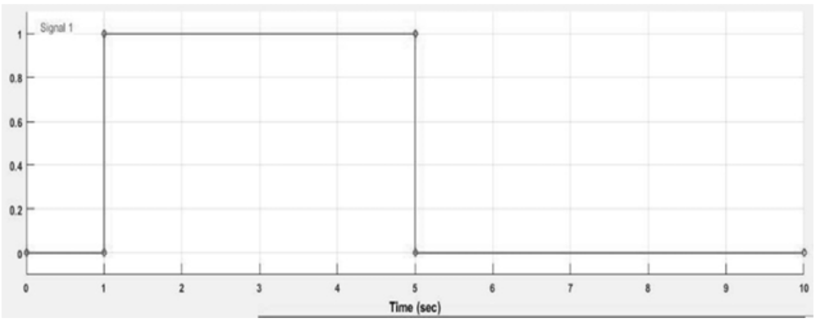

Fig. 7. The form of the control signal of the load-bearing mechanism

The simulation was carried out at a load of 10,000 kg. As a result were obtained model parameters such as vibrational displacements, velocities and accelerations of the main and end beams and the stresses caused by them. The results are shown in the next section.

5. Results of the research

Below there are the results of combined simulation, the design of the overhead traveling crane in the form of dynamic response at specified points, to the applied kinematic action, as well as the results of the investigation of the natural frequencies of the crane. Dynamic deviations were determined using the Matlab-Simulink software for the phenomenological model described in Section 4. A fast Fourier transform was used to determine the fundamental frequency of the structure's oscillations at specified points. Location scheme of measurement points in the model FE, is shown in Fig. 8.

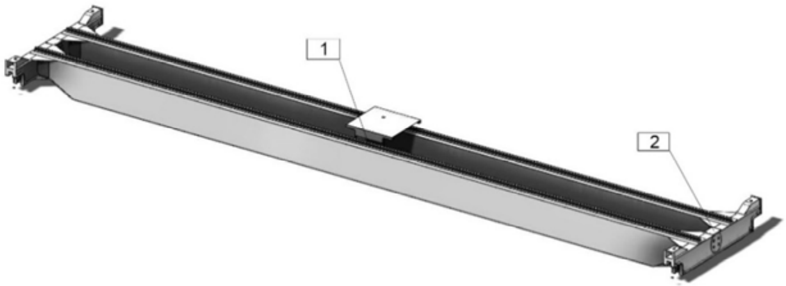

Fig. 8. Scheme of vibration measurement signals in FEM

Calculations were carried out in the SolidWorks software. Figure 9 shows the shape of the deformation of the supporting structure under the action of the excitation amplitude.

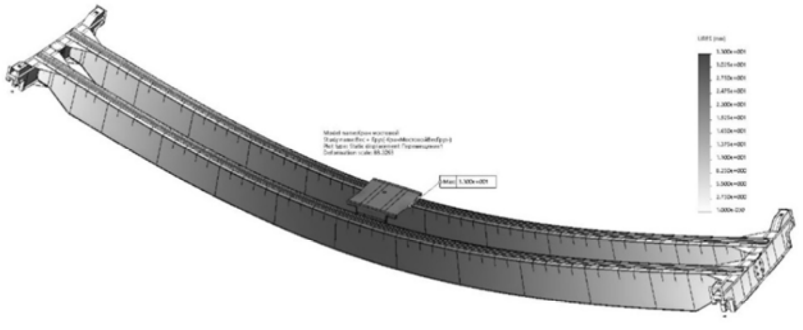

Fig. 9. The shape of the construction bend under the influence of the maximum load amplitude.

In Fig. 10-12 show the curves displacements, velocities and acceleration, obtained on the basis of vibration calculation in FEM.

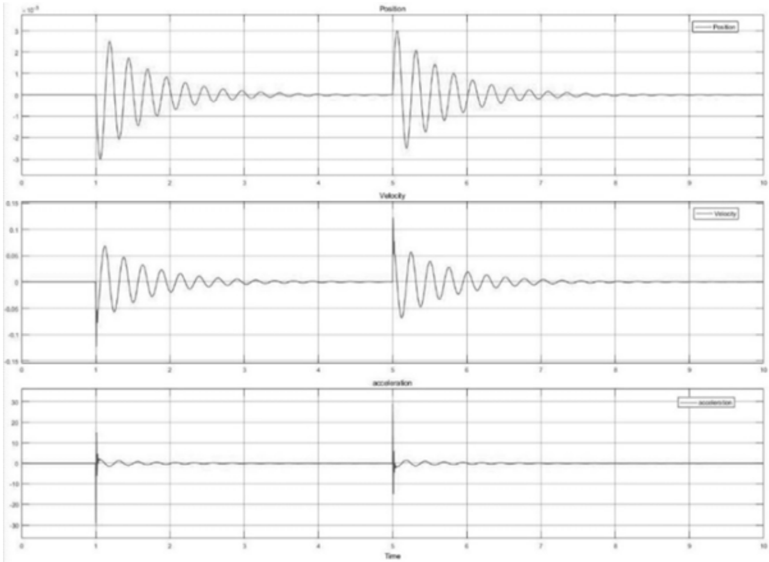

Fig. 10. Curves of deviations, velocities and acceleration due to vibration at point 1

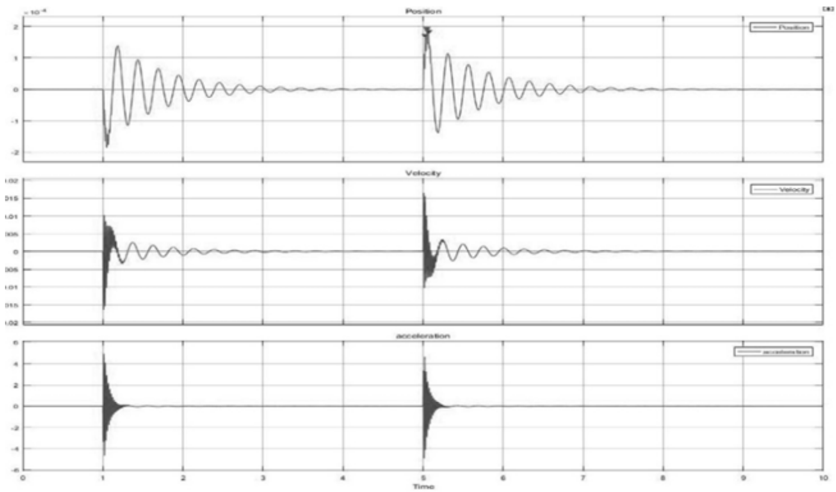

Fig. 11. Curves of deviations, velocities and acceleration due to vibration at point 2

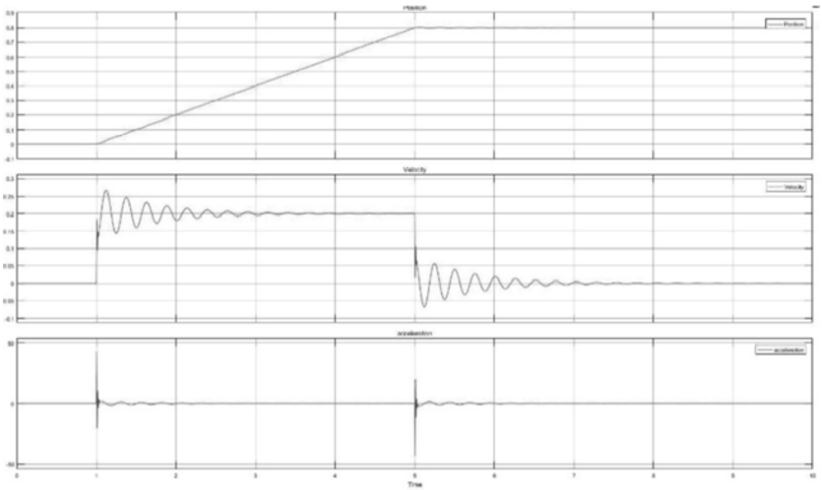

Fig. 12. Curves of deviations, velocities and acceleration of cargo

The results diagram of natural oscillations in the FEM are shown in Fig. 13-18.

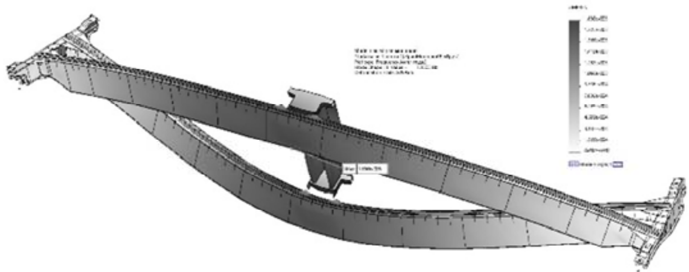

Fig. 13. Diagram of the resulting amplitude for the waveform 1

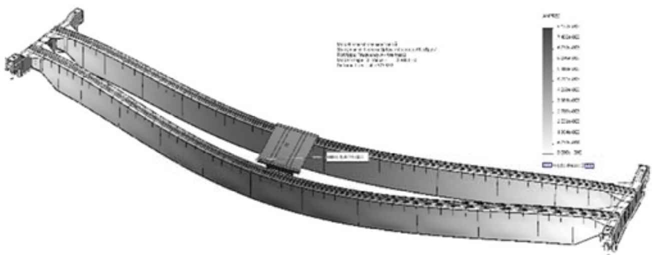

Fig. 14. Diagram of the resulting amplitude for the waveform 2

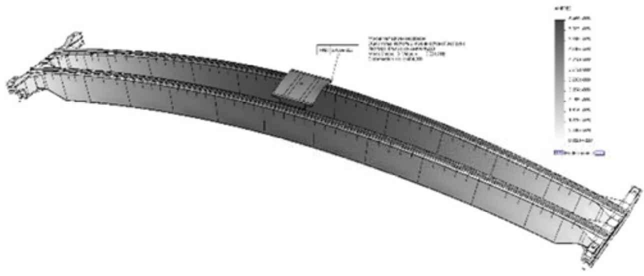

Fig. 15. Diagram of the resulting amplitude for the waveform 3

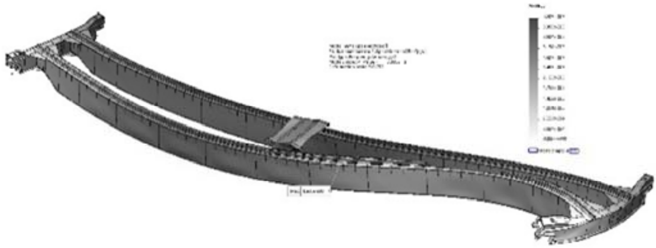

Fig. 16. Diagram of the resulting amplitude for the waveform 4

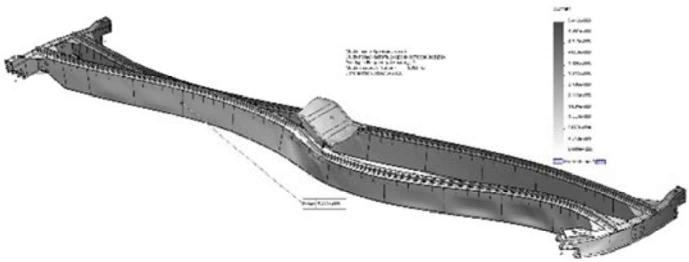

Fig. 17. Diagram of the resulting amplitude for the waveform 5

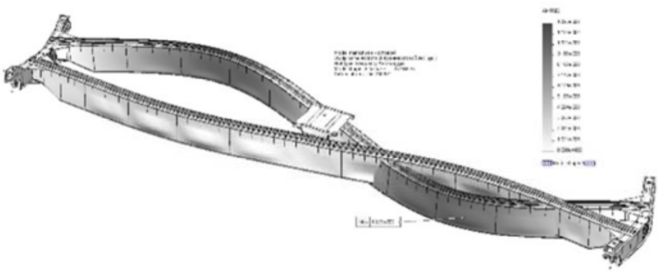

Fig. 18. Diagram of the resulting amplitude for the waveform 6

The results of studies of natural oscillations in the FEM are shown in Tables 6, 7 and 8.

Table 6

List of natural frequencies of the overhead traveling crane

Number mode	f, Hertz	
	Construction without cargo	Construction with cargo
1	2.8244	2.9883
2	3.7283	3.0316
3	4.8225	3.835
4	6.2857	6.3515
5	8.5768	8.7684
6	9.1286	9.1296

Table 7

Mass participation of the model in oscillations relative to the axes of the local coordinate system (construction without load)

Number mode	Frequency (Hertz)	Direction X	Direction Y	Direction Z
1	2.8244	0.018701	4.4537e-007	0.67763
2	3.7283	0.015267	0.76082	0.00027284
3	4.8225	0.86971	0.011703	0.0079799
4	6.2857	0.00019662	5.2563e-007	4.2417e-005
5	8.5768	0.0001223	2.0593e-007	1.1517e-007
6	9.1286	0.029764	4.1068e-005	6.3598e-006
		Σ X = 0.93376	Σ Y = 0.77256	Σ Z = 0.68593

Table 8

Mass participation of the model in oscillations relative to the axes of the local coordinate system (construction with load)

Number mode	Frequency (Hertz)	Direction X	Direction Y	Direction Z
1	2.9883	0.069874	0.062469	0.36831
2	3.0316	0.0013032	0.7358	0.039405
3	3.835	0.72902	0.010043	0.023924
4	6.3515	0.12187	0.00033852	0.00037539
5	8.7684	0.0015358	3.5804e-006	2.88e-011
6	9.1296	0.022679	6.6803e-005	7.9101e-006
		Σ X = 0.9716	Σ Y = 0.80873	Σ Z = 0.74872

The analysis of the obtained results allows to conclude that the most significant are the oscillations along the Y axis (vertical axis) and the Z axis (along the crane girder). Vibrations along the X axis (along the main beam) are significant only at a frequency of 3,83 Hz. On the Y axis, the most mass effect is provided by the frequency of 3,03 Hz, Z axis = 2,98 Hz

The results show a significant mass participation of the structure in oscillations at frequencies from 2,9 to 3,8 Hz. According to [18], it is precisely these exciting frequencies that are characteristic of overhead traveling crane when lifting and lowering loads. The coincidence of the exciting and natural frequencies can lead to resonant phenomena, negatively affect the parameters of reliability and durability.

A fast Fourier transform made it possible to isolate the fundamental frequencies of the dynamic model of the crane at given points. The frequency of primary oscillations occurring at the center of the main beams is 3,5 Hz, in the direction of lifting the load. The frequency of primary oscillations in the center of the end beams is 55,3 Hz.

The frequency of 3.5 Hz at the load securing point coincides with the intrinsic vibration frequency of the crane determined in the SolidWorks system, which confirms the accuracy of the analysis. Studies carried out with other models of overhead traveling crane [19] confirm the high convergence of the data obtained as a result of testing real objects and the results obtained in the complex analysis of mathematical models.

When working on a overhead traveling crane there is a low-frequency vibration of 3.5 Hz. The same magnitude of vibration is also the frequency of primary oscillations in the center of the main beams of the overhead traveling crane, as well as in the places of fastening the load. Low frequency vibration in the range of 0.01 - 16 Hz, which includes a value of 3.5 Hz, negatively affects the metabolic processes in the human body: changes the carbohydrate metabolism, biochemical parameters of blood, which leads to a violation of the protein, enzymatic, vitamin and cholesterol exchanges.

General vibration with frequencies of 1 - 250 Hz is dangerous for the internal organs of a person, because it can coincide with their own frequency of oscillations. As a result, there is a resonance that leads to displacements and mechanical damage to the internal organs. Resonance of the human body occurs at frequencies greater than 0.7 Hz. For work in a sedentary position - for the entire human body - 4-6 Hz, the resonance frequency of the head is 2-3 Hz at vertical vibrations, and at horizontal 1.5 - 2 Hz. The magnitude of the vibration with frequency 60 ... 90 Hz causes serious disturbances of visual perception (resonance of eyeballs). The frequency of vibration in the range of 200 - 250 Hz negatively affects the central nervous system. The whole human body has a frequency of its own oscillations ~ 8 Hz; external oscillations with frequencies of 17 - 25 Hz are resonant for the human head [1]. For example, for a person's head is negatively affected by vibration with a frequency of 1 - 20 Hz. For the organs of the chest, diaphragm and abdomen are resonance frequencies of 3 - 4 Hz, for heart - 5 - 6 Hz.

Prolonged action of vibration, can lead to the development of occupational disease - a vibration disease that is accompanied by irreversible changes in many systems of the organism. The complexity of treatment of a vibration disease is that it belongs to a group of diseases, effective treatment of which is possible only at an early stage of disease [20]. Simultaneous action of increased noise and vibration, cooling of the whole body or extremities deepens the disease. During development of this disease there is numbness, joint pain, feeling of crawling ants. The greatest danger of the development of a vibration disease occurs when exposed to vibration with an amplitude of oscillations of 0.101-0.3 mm and a frequency of 16 - 250 Hz.

Conclusions

The technique with more accurate and cost-effective way to predict crane’s responses to the dynamic actions, particularly load-lifting and load-lowering, is offered.

The impact of the different vibration frequencies on the overhead traveling crane driver is analyzed.

The capability to analyze the influence of the machinery parameters and structural elements on the crane vibration and the vibration of its components was got on the drawing-board stage. This makes it possible to raise construction durability and improve working conditions.

The presented models of FEM and rigid masses can become the basis for further studies based on an integrated approach that integrates the dynamic model with the FE model.

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ANALYSIS OF GLOBAL TRENDS IN THE CHANGE OF TRAUMATISM IN THE MINING INDUSTRY AND THE DEVELOPMENT OF WAYS IN REDUCING IT IN THE COAL MINES OF UKRAINE

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Abstract

Despite the annual increase in investment of projects to increase the level of labor protection in basic industries, the development and implementation of strategic safety programs within enterprises, industrial groups and at the state level, the mining industry remains the most dangerous among all sectors of the economy.

The maximum capitalization of the extractive industry in the world is observed in the coal, copper, iron ore and gold mining sectors. The same sectors bring the maximum profit among solid mineral resources. Coal confidently occupies the first position, providing up to 30% of the planet's energy potential. Such a situation according to the forecast of the International Energy Agency will not change for the next 20 years.

Ukraine is among the top twenty of the countries-leaders in coal mining, being a representative of the countries of medium-level technical capacity. Therefore, increasing the safety level of work in the coal mining sector of Ukraine is quite important and urgent task. The developed and implemented methodology for estimating underground coal mining from the point of view of its safety allows us to give a deep and comprehensive assessment of mining production, outlining ways to reduce the accident rate and then shifting the minimization of costs for safety in the industry.

For the formation of the initial material base of state insurance agencies the forecast of the level of traumatism at coal enterprises of the relevant region was first used by modern methods of mathematical statistics.

A method for estimating and subsequently predicting possible traumatism for workers in the coal industry has been developed which makes it possible to assess the nature of the dynamics of this production factor and to plan work, both technically and socially, based on ensuring the necessary level of social insurance in the industry.

Introduction

The number of fatal accidents, serious injuries and long-term disability in the mining industry remains the highest in the industry. At the same time, the state of the level of labor protection despite the constant improvement and implementation of all new measures and requirements for safety remains unsatisfactory and does not comply with the accepted social standards.

The maximum profit from the sale of mineral resources (excluding oil and gas) in the extractive industries of the whole world is provided in the following sectors, shown as profits decrease: coal, copper, iron ore and gold.

At the same time, coal provides about 27% of the world's electric power production, and, for example, China's coal producer with a production of 3.68 billion tons, 70% of primary energy is extracted from coal [1, 2]. Demand for coal has not declined for a long time, despite the changing course of the energy policy towards green energy and renewable sources. According to the forecasts of the International Energy Agency the demand for this type of fuel existing in the latest decade will not be reduced within the next 20 years.

1 Analysis of global traumatism indicators in the extractive sector

The technology of the underground works at the enterprises of different countries is fundamentally different in the level of mechanization, the ratio of energy used, the scale of production and the state of labor protection. Innovative policy and security policy, regulatory and legal framework for investigating the causes of accidents and providing insurance payments also differ. Therefore, the statistical indicators of security of different countries are very different. The bulk of the world's mineral resources are extracted from high-performance enterprises in large and medium companies. However, small mines, and mines with a large share of manual labor, employing about 15 million people only in Asian countries [3], also contribute a significant share in world production. At such enterprises, the level of labor protection remains consistently low for more than half a century, traumatism is generally not taken into account, and products are delivered to illegal markets. In the below indicated analysis such enterprises are not taken into account, the main attention is paid to enterprises that have a level of production close to the domestic mines.

The top ten countries for the extraction of mineral raw materials are as follows: China, USA, Australia, Canada, India, Chile, RSA, Brazil, Russia and Japan [2]. According to the first 8 countries, there is official statistics on injuries in the open access, it is absent in Russia and Japan. The countries that occupy the world's leading positions for the extraction of hard coal, other than those mentioned above, include Indonesia, Iran, Poland, Turkey and Ecuador. Ukraine before the starting of hostilities was one of the top ten coal mines with annual production volumes approximately 80 million tons. This fact indicates a fairly high level of the domestic coal industry.

Over the past decade these 15 countries have provided about 50% of the world's total production of the solid minerals. Therefore, an analysis of the level of injuries in these countries can be considered indicative for obtaining information on the level of safety and clarifying its main causes.

It is well known that working conditions in the mining industry are characterized by physically difficult work, insufficient illumination of the working space, high noise level, hazardous conditions associated with insufficient stability of underground structures, heavy tools and complex equipment, risk of major accidents, impact of toxic dust, chemicals, temperature.

In the most developed countries, there is a legal regulatory framework that includes specific acts, codes or regulations concerning safety and health in the mining industry. However, there is no such special legislation from the above-mentioned list of countries in Turkey and Iran. In other countries, regulatory and legal acts regulating work in the mining sector are generally similar to those in Ukraine, which simplifies the analysis and improves its reliability.

Annually, more than a thousand miners get fatal injuries and lose their ability to work for different periods. The main causes in the investigation of accidents are gas or dust explosions, gas poisoning, careless handling of explosives, electric shock, collapse of underground structures, collapse of the roofing, flooding, falling people, mechanical traumatism be the working equipment.

The largest number of the miners - about five million people is employed in the Chinese mining industry. Over the past 60 years in China 250 thousand miners died as a result of the accident. However, the level of traumatism there with the inadequately high gradually decreased, according to the world trend, to the average. From 2002 to 2012 the number of deaths decreased from 6,995 to 1384. This is mainly due to the increasing of the level of work mechanization. The main causes of the fatal injuries in China are: explosions and fires - 43%; collapse of the roofing - 33%; flooding excavations - 8%; and coal transportation - 9% [4].

The USA with a stable level of coal output of about 900 million tons in recent years is the second largest in the world. The US mining industry is developing in three different sectors: coal, metal and non-metallic, natural stone, sand, crushed stone. In the USA, the management of the enterprise is responsible for the safety and health of miners according to the legislation. In addition, two US Federal Agencies have additional responsibilities to promote the safety and health of the miners. Mine Safety and Health Administration (MSHA) located in the Labor Department is legally responsible for developing and enforcing mining regulations, also approving and certifying certain equipment used in mines. The MSHA budget is approximately $ 360 million, and the staff is approximately 2,400 people.

The total number of employees in the extractive industry is 231 549 employees, in the coal industry 86 000 miners. The rate of fatal injuries per 100,000 workers over the past decade in the United States was between 30 and 12. The structure of non-fatal injuries according to MSHA information [5] is following: processing materials - 29%, people falling - 19%, caving - 16%, machine working - 12%, hand tools - 6%.

In India that extracted 605.1 million tons of coal in 2017, the rates of injuries in coal mines are lower than those on non-coal mines. So the total number of fatal injuries for the past decade for coal mines was 102 miners with a 0.21 fatal injury rate (FVT), and 65 people in the non-coal sector at FVT 0.34 [6].

Australia is very rich in mineral resources. It ranks first in the world for the extraction of brown coal, lead, zircon, rutile, nickel, uranium and zinc, the second in bauxite, copper, gold, silver, ilmenite and titanium, the third in industrial diamonds, and the fourth in coal, iron and manganese ore [7]. Coal mining in 2017 was fixed at the level of 478 million tons.

The level of occupational safety and health in Australia is very high. Requirements are strictly regulated by legislative acts. Only 0.3% of the accidents are fatal. The total annual number of fatal injuries during the past decade ranged from 7 to 18. The level of traumatism per 100,000 miners is 7.

The distribution of injuries for the past decade for the reasons for injuries is following: falls, injuries along the way to the workplace, physical contact with a moving or stationary object, and material handling accounts for about 79% of injuries, muscle tension as one of the main causes in 26% of injuries, falling from a height of 7% [8].

In Indonesia, coal, tin, nickel, gold, bauxite, silver and copper are mined. The country took the fifth place in the world in 2017 with a coal production of 421 million tons. The total number of industrial injuries in the previous decade fluctuated between 4429 and 14487, not counting non-state, illegal mines [9]. Data on fatal injuries are not available for analysis.

Iran is one of the 15 most rich in minerals, the country produces about 68 different minerals. The main causes of fatal injuries in Iran are [10, 11] mining machines - 29%, rock collapse - 22%, explosions - 10%, destruction of underground structures - 8%, falling objects - 7%, thermal damage - 5.5% electric shock damage - 5%, gassing 4.5%. The National Social Insurance Organization report includes 14,114 occupational accidents with 868 deaths among insured persons in 2001 [12]. Concerning the above-mentioned accidents - 641 occurred in the mining sector [11].

The predominant number of the mines in Poland are engaged in the extraction of hard coal. Poland occupies the 8-th place in coal mining with 142.9 million tons of coal. In the coal sector FVT for the period 2005-2011 is in the range of 0.15-0.46 [13, 14].

The underground mines in Poland, as a rule, meet the most modern level of the development. The main causes of fatal traumatism for the past decade were injuries along the way of movement to the workplace - 38.5%, in underground transport - 27.1%, electric shock damage - 21.4% near the mining machines [13, 14].

The mining industry of Turkey works in the sectors of extraction of aluminum, coal, phosphorus, chromium, copper, uranium and gold [15]. Over the past 5 years in the mining enterprises of Turkey recorded 30154 cases of injuries. In 2010, the number of fatal traumatism was 130, and injuries with disability received 76 miners [16].

RSA is a middle-income country and the dominant economy on the African continent. The country produces 53 different minerals at 1,548 mines [17]. The number of miners engaged in the extraction of coal, gold and platinum at the end of the latest decade was 78012 people. Despite the developed mining industry, the level of labor protection and safety in the industry is much lower than world standards. This is largely due to the large number of small mines, with a low level of mechanization. Over the past decade, the level of fatal traumatism in South Africa in the coal industry ranged between 1.5-5.1, and the incidence of injuries with disability was 31.8-50.9 per 10,000 workers [18, 19].

Canada is the world's largest producer of uranium and potash, the second largest producer of nickel and cobalt, the third for the production of titanium concentrate, platinum group metals and aluminum, the fifth largest diamond, chrysotile, zinc, molybdenum and salt mining.

The current safety standards, regulations and occupational safety standards of Canada are the highest in the world.

The total number of miners employed in the mining industry of Canada is about 18,000. The average incidence of casualties in Canada over the past decade is 0.5 to 200,000 hours.

The main danger of injury traditionally threatens the Canadian miners: falling rocks, injuries from moving parts of machines and mechanisms, injuries while working with equipment.

In Brazil, 11% of the world's iron reserves are concentrated, it occupies the fifth place in the world. In addition, Brazil provides 10% of the world's bauxite, 12% magnesite and 10% manganese occupying these positions at the second and third place in the world. At the end of the past decade, the total number of workers in the mining industry of Brazil was 156 254 people. The level of lethal traumatism in the mines at the end of the decade was 28.96 cases per 100,000 miners [20].

Chile has important reserves of minerals and mining activities. Mineral reserves include copper, molybdenum, manganese, lead, zinc, silver and gold. More than 80% of natural resources are copper ore.

At the end of the past decade, Chile's mining industry employed 191,000. 48% from this number work in large mining companies, 46% in medium enterprises and only 6% in small companies [21]. The level of fatal injuries has traditionally been at around 0.1 per 1 million working hours. The incidence of annual traumatism with disability in the past decade in Chile was 4.09-9.5 cases per 1 million workers.

The causes of fatal injuries are accidents caused by landslides, electric shock damage, explosions, choking and falling from the height [22].

Gold, silver, copper, molybdenum, iron and zinc are mined in Ecuador. Most of the products are in small mines. At the same time, most of the enterprises are in the informal sector. In this regard, there are no exact statistics on the industry. According to 2010 estimates, about 60,000 miners are employed in small mines [23]. In the mining industry of Ecuador there is no specific statistics of injuries and diseases. However, it is known that fatal injuries in mines are mainly due to the lack of security measures in underground mine workings.

The coal industry of Ukraine is the most complex and most traumatic industry of the economy. According to the Social Insurance Fund in 2017 the share of accidents in the extractive sector is 18.9% (936 people are injured, 31 of them are fatal) [24]. In the list of the most risky occupations in terms of occupational injuries were: a miner of the face output, a driver of the vehicle and a sinker.

The distribution of fatal injuries (traumatism) in the Ukrainian coal industry is shown in Fig. 1.1.

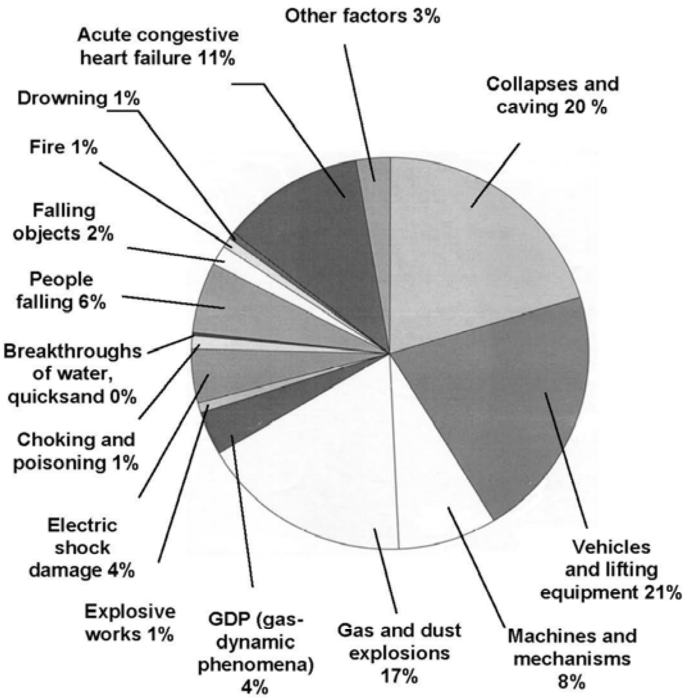

Fig. 1.1. Distribution by the factors of fatal traumatism by the industry

Now let's compare the safety indicators in the international mining of four countries from the top ten leaders of the underground mining with different rates of production and injuries: The United States of America, South Africa, Canada, Australia. The information is taken from the report of the Committee on Minerals [25].

It is known that various criteria are used to analyze data on injuries. These criteria are presented in the above- mentioned analysis of traumatism in 15 producing leading countries. The collection of statistical information in different countries is determined by the legislative framework, and therefore the criteria for assessing security do not always coincide. As the criteria for comparison, the most popular indicators of FVT and the coefficient of working time losses are adopted (Figures 1.2, 1.3).

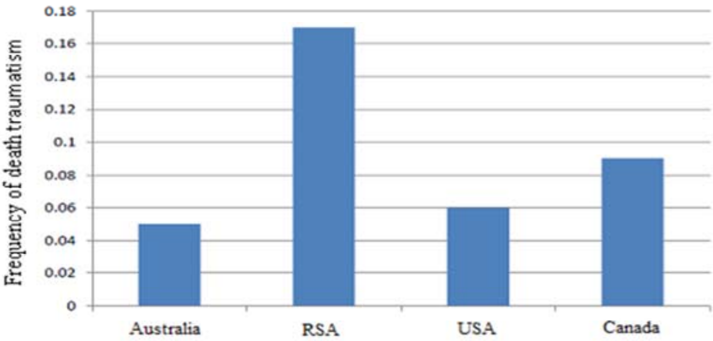

Fig. 1.2. The frequency of death traumatism in countries from the TOP-10 of the underground mining

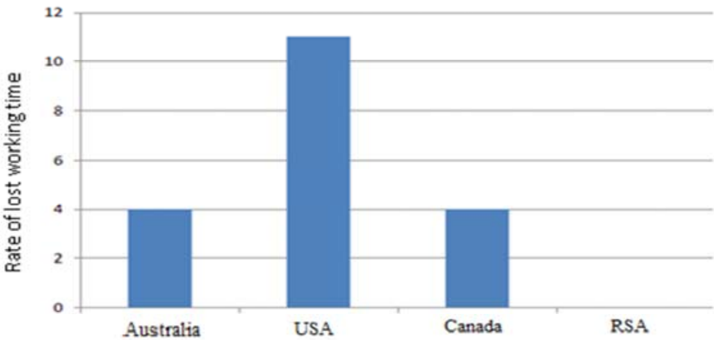

Fig. 1.3. Rate of lost working time in the countries from the TOP-10 underground mining (for RSA there is no information)

Fig. 1.1 shows that the death rate is minimal in Australia 0.05, then the USA - 0.06, Canada - 0.09 and the maximum in RSA - 0.17. In contrast to fatal traumatism, the loss factor of working time in Canada is less than in the US (Figure 1.3). This can be explained by the differences in the legislative acts of health and insurance, the information on which is given above.

Fatal traumatism and traumatism with disability are associated both with an anthropomorphic factor that takes into account human behavior, non-compliance with the rules and requirements of safety rules, deficiencies in the management system and inappropriate management decisions, and with natural factors associated with the specific environment in which these or other production operations.

Since the analysis of the safety indicators of the domestic coal industry and their comparison with the indicators of the mining enterprises of the world is analyzed below, the study takes into account the safe environment conditions of coal mines, the assessment of accident risks, management shortcomings, the psychophysical condition of the miners, the accumulation of fatigue and insufficient level of professional knowledge and skills leading to a violation of safety requirements.

If you compare the above-mentioned countries on the complexity of mining and geological conditions, it is obvious that the most favorable production conditions in Australia and the United States, and the most difficult in South Africa (RSA). The depth of the working horizons of the South African mines reaches 4 km, which, with a sufficiently high level of labor intensity, causes traumatism in the performance of the main technological cycles. High humidity and high temperature of rocks and mine atmosphere cause problems with ventilation, flares and explosions of the gas-air environment.

There are 167 deaths in 2009 in absolute terms in the mining industry of South Africa for example. At the same time, their number is steadily decreasing. For comparison, in 2009, 18 people were fatally injured in Australia, 29 in the US, and only 3 in Canada.

The best safety performance is characteristic of Australia in large part due to the more favorable mining and geological conditions and the state policy of the country. Analyzing the dynamics of the change in the frequency of fatal injuries and the loss of working time over 10 years by the example of the Australian extractive industry (Figure 1.4a, b), it can be concluded that non-fatal injuries naturally decrease year on year, thanks to state support and investment of safety enhancement projects, but the fatal traumatism does not have a clear tendency, that is, it is a more random process (Figure 1.4 b).

For Australian mines, with relatively favorable mining and geological conditions, the human factor is the determining cause of injury, including fatalities in the mining industry. This conclusion is confirmed by both security researchers [26] and inspection authorities [27].

Thus, the conclusion is logical that in countries with more favorable mining and geological conditions, with the absence of causes of a catastrophic nature (the development of which is highly dynamic and leads to mass accidents), the main part of injuries is associated with an anthropomorphic factor.

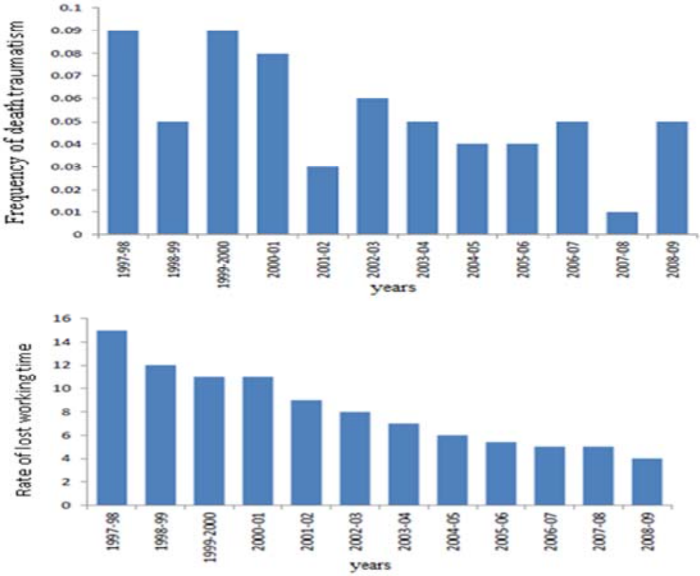

Fig. 1.4. The dynamics of the change in the frequency of fatal traumatism (a) and the loss factor of working time (b) in Australia

At the same time, in countries with the presence of such factors that develop minerals in complex mining and geological conditions, the overall indicators of injuries differ by a factor of tens. And the higher the level of scientific research in the industry the more regulatory and legislative acts and the greater the investment in security, the lower the level of injuries. Positive examples are the United States and Canada.

Thus, the conclusion is obvious about two promising directions in increasing the rates of injuries in Ukraine:

- a comprehensive study of the environment in which work is conducted, from which the tasks of safety forecasting, analysis of the probability of occurrence of accidents, the development and timely implementation of measures to reduce the likelihood of occurrence and development of emergency situations follow;

- improving the system of investing in security based on the development of a scheme for conducting locally oriented investments in the most risky areas of specific enterprises, as identified by a preliminary forecast.

In this vein the task of forecasting emergencies and analyzing the risks of accidents is of exceptional importance and is one of the priority areas of research.

2. The ergative system of the "man-machine-environment" type

It is known [28, 29] that, both in Ukraine and abroad, the public is not overly concerned about the existence of a risk of 10-6 per year or less, so measures are rarely applied for its subsequent reduction. The level of individual risk with a fatal outcome (per year) is due to various types of hazards [29]: Ground transportation-$3\cdot10^{-4}$; The fall from the height - - $9\cdot10^{-5}$; Fire or burn - - $4\cdot10^{-5}$; Drowning - $3\cdot10^{-5}$; Poisoning is $2\cdot10^{-5}$; Mechanical equipment - $1\cdot10^{-5}$; Falling objects - $6\cdot10^{-6}$; electric shock - $6\cdot10^{-6}$; Railway transport - $4\cdot10^{-6}$; Lightning - $5\cdot10^{-7}$; Hurricane - - $4\cdot10^{-7}$; Other factors - $4\cdot10^{-5}$.

Assuming on the basis of preliminary analysis and domestic standards the permissible level of risk with a fatal outcome of 10^{-6} per a year, it should be taken into account that the risks assumed by the individual voluntarily (for example, in sports), which can reach 10^{-2} – 10^{-3} for year are not related to workplace safety. These approaches are applicable to the description of similar situations in other industries (for example, metallurgy, coke chemistry), but the structure that contributes of an emergency is completely different here.

Studies show that the process of an accident of a sufficiently large scale consists, as a rule, of two parts: man-machine or machine-environment. And the human factor in direct or indirect form is present practically in all cases. Since the second most important factor is equipment, it follows from the foregoing that at present there are ways to reduce accidents at mines, including those dangerous for gas or dust emissions, through targeted training of personnel and ensuring the working condition of mining equipment

Attempts to assess the safety in the mine were made, in particular, with regard to underground power supply systems [30, 31], mining equipment by the maintenance mode planning [32], and also the state of the mountain massif, i.e., directly the environment [33]. It was these works that served as the basis for a new scientific direction that allowed establishing a numerical relationship both between the constituent parts of a coal mine, dangerous for gas or dust emissions, and an ergatic object such as man-machine-environment.

Initially, when researching complex systems, since coal mines, safe work at a certain point was traditionally identified with reliability. However, later the illegality of such identification was revealed: if in the theory of reliability attention is mainly paid to technology, then the main object of the security of the system is a person.

Increasing reliability certainly contributes to increased safety, although this only applies to equipment that can be the source of an emergency. Thus, failure of a lamp in a substation chamber with individual luminaires for personnel generally cannot create danger for people, which means that it cannot be the source of an emergency situation. However, the deviation of the environment from the optimal when changing the mining and geological conditions at the mine, for example in the case of a sudden release, can lead to an emergency situation, although failures and breakdowns of industrial equipment in this case were not observed. Thus, the premise of failure is a defect, and the premise of an accident is a deviation from the normal operation of people and mine equipment or from the normal state of the environment.

3. Methods for obtaining data concerning the work of the coal industry

Turning back the retrospective view to the past, it can be recalled that earlier, I emphasize that all data, without exception, on accidents and injuries in the coal industry certainly came to the relevant organizations (MakNII, Mine Military Rescue Brigade), where they were processed in due course, in connection with that the industry had objective information on almost all issues of production [34].

Therefore, proceeding from the considerations that the coal industry is sufficiently conservative (new technologies have not been introduced in recent decades), as factors influencing both the process of underground coal mining and its safety, on the basis of already the available experience [35, 36] can be addressed by the following phenomena:

1. Traumatism related to transport.
2. Traumatism in the maintenance of stationary mechanisms.
3. Electric shock.
4. Explosion.
5. Collapse.
6. Gassing.
7. Fire.
8. GDP (gas-dynamic phenomena).
9. Other.

So, to start with the analysis, you can take all of the above factors, and then add or remove from the calculations and analysis some of them, using the methods of classical high-level statistics.

Since, as mentioned earlier, regular collection of data on the accident rate in the industry has been absent for many years, then other methodological approaches are needed to solve the problems arising in the coal industry. As such a method, expert judgment can be used [37], which has already been widely used [38, 39] to assess the state of the mine as an ergative system of the type: "man-machine-environment".

It is known that expert evaluation (or value) is a procedure for obtaining an assessment of the problem on the basis of the opinions of experts (specialists) with a view to a subsequent decision [40].

The following stages of expert evaluation are available:

- Statement of the research objective
- Selection of the research form, definition of the project budget
- Preparation of information materials
- Selection of experts
- Examination
- Analysis of results (expert evaluation processing)

There are two groups of expert assessments:

- Individual assessments, which are based on the use of the views of individual experts, independent of each other.
- Collective assessments, which are based on the use of collective opinion of experts.

A joint opinion is more accurate than the individual opinion of each of the experts. This method is used to obtain quantitative estimates of qualitative characteristics and properties.

4. Forecast of the level of injuries at coal enterprises

Defining initially the dynamics of injuries and occupational diseases at the coal enterprises. To do this, from the general data on the need to exclude the impact of statistics of occupational diseases and injuries, as well as the dynamics of injuries and occupational diseases, not related to the activities of coal enterprises. At the same time, we will exclude the influence of demographic and epidemiological factors that influenced the increase in traumatism in the region, by calculating the rates of increase in injuries in the area, by calculating the rates of increase in injuries and occupational diseases that are not related to the activities of coal industry enterprises, and we will correct the dynamics of increase in injuries and occupational diseases at enterprises coal industry.

In most cases, the predictive function is an exponential dependence [41], the parameters of which are determined on the basis of [42]

$$x(t) = ae^{bt}, \tag{1}$$

where *x (t)* is the magnitude of the traumatism rate for time t from the first year of the preceding decade; *a, b* are constant coefficients; *t* is the time elapsed from the first year of the preceding decade, years.

The coefficients *a* and *b* are determined by the following dependencies:

$$b = \frac{n\sum_{i=1}^{n} t_i \lg x_i - \sum_{i=1}^{n} t_i \sum_{i=1}^{n} \lg x_i}{\lg e\left[n\sum_{i=1}^{n} t_i^2 - \left(\sum_{i=1}^{n} t_i\right)^2\right]} \tag{2}$$

$$\lg a = \frac{\sum_{i=1}^{n} t_i^2 \sum_{i=1}^{n} \lg x_i - \sum_{i=1}^{n} t_i \sum_{i=1}^{n} \lg x_i}{n\sum_{i=1}^{n} t_i^2 - \left(\sum_{i=1}^{n} t_i\right)^2}, \qquad (3)$$

where x_i - the value of the index of injuries for the i-th year; t_i - the time elapsed from the first year of the preceding decade to the i-th year; *n* is the number of observations.

An error in the predicted values of the traumatism rate is calculated on the basis of the following relationship

$$m = \pm \frac{\sigma}{\sqrt{n-1}} \sqrt{1 - \frac{n(t_j - k)^2}{\sum (t_i - k)^2}}, \qquad (4)$$

where σ - root-mean-square deviation; t_i, t_j - the time elapsed from the first year of the preceding decade, respectively, to the i-th year of this decade and to the j-th forecast year;

$$k = \frac{1}{n} \sum_{i=1}^{n} t_i . \qquad (5)$$

The value of the root-mean-square deviation is determined from the following relationship [42]:

$$\sigma = \sqrt{\frac{1}{n-1}\left[\sum z_i^2 - \frac{1}{n}\left(\sum z_i\right)^2\right]} \qquad (6)$$

The predicted values of the injury rate are calculated on the basis of the following relationship:

$$x_T = ae^{bT} \pm m, \qquad (7)$$

where T - is the time elapsed from the first year of the preceding decade to the forecast year.

If the actual values of the traumatism rate in the year for which the forecast was made will be within the limits calculated according to formula (3) or less, this indicates that the traumatism rate remained at the same level or decreased; if the actual values are higher than the calculated values this will indicate to the increasing in injuries in specific production conditions.

Using the methods of parametric and nonparametric statistics, and in particular of correlation and regression analysis, it is possible to derive and analyze a number of dependencies that enable them to perform a comprehensive assessment of the process of industrial traumatism at the site and to outline the optimal ways to reduce the cost of payments.

As a result, we can conclude that, as the work intensity increases, the level of injuries increases, and, as a consequence, the number of payments to the victims. However, depending on the particular enterprise, even if there are very identical mining and geological conditions, the costs of social insurance of one worker (the average actual severity of injury) can differ by 2 or more times. Further increase in the intensity of production requires training, both personnel, in terms of teaching it safe working methods, and introducing new technology with an increased level of safety. In this case, the dynamics of growth for social insurance will have a strong tendency to a permanent decline.

Conclusions

The methodology developed for the assessment of underground coal mining from the point of view of its safety allows us to give a deep and comprehensive assessment of mining production, outlining ways to reduce the accident rate and then shifting the minimization of costs for safety in the industry.

For the formation of the initial material base of the state insurance bodies, the forecast of the level of injuries at coal enterprises of the relevant region was first used by methods of mathematical statistics.

Correct execution of calculations became possible with the use of modern high-level statistics methods for this purpose, in particular, methods of nonparametric statistics, since they gave the most accurate approximation of the results obtained with their help to the actual production data obtained in the industry, industrial injury and its reasonable forecast.

In general, it should be noted that a method has been developed for assessing and subsequently predicting possible injuries for workers in the coal industry, which makes it possible to assess the nature of the dynamics of this production factor and plan work both technically and socially, based on ensuring the necessary level of social insurance in the industry.

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