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ANALYSIS OF POSSIBILITIES TO REDUCE THE RATE OF ACCIDENTS IN COAL INDUSTRY OF THE RUSSIAN FEDERATION

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АНАЛИЗ ВОЗМОЖНОСТЕЙ СНИЖЕНИЯ ПРОИЗВОДСТВЕННОГО ТРАВМАТИЗМА В УГОЛЬНОЙ ОТРАСЛИ РОССИЙСКОЙ ФЕДЕРАЦИИ

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coal, section, quarry, mine, excavator, accident, zero accident, electric accident, electric current, protective means, protective grounding, automatic control, step voltage, touch voltage, protective grounding resistance, grounding conductors.

The dynamics of coal mining development in the world and Russian Federation is estimated. Incident rates in coal mining is analyzed. The subject of the study is the coal industry of the Russian Federation. The purpose of the study is to identify possible ways to improve the safety of personnel working in the coal industry of the Russian Federation. The research objectives are as follows: to identify promising directions for development of the coal industry; to conduct an analysis of incidents in the coal industry of the Russian Federation; to conduct a comparative analysis of the level of safety in coal mining in the Russian Federation and other industrialized countries; to identify the main causes of injuries in the coal industry of the Russian Federation; to analyze the available means of protecting the personnel of the coal industry of the Russian Federation from electricity and identify opportunities for their improvement. The research methods are as follows: analysis of statistical information on coal mining in the Russian Federation and world; patent search for devices that protect workers of the coal industry from effects of electricity.

The papers refers that the level of accidents in underground coal mining in the Russian Federation is significantly higher than in coal mining in coal sections. It is noted that the amount of underground coal mining in the Russian Federation have not changed in recent years, and the volume of open-pit coal mining is growing. The main causes of accidents in the coal industry of the Russian Federation are identified. The cases of accidents from electricity are considered in detail. The main technical means ensuring protection of a person from electric shock during coal mining in coal mines are analyzed. A patent search for existing devices for monitoring the continuity of the ground wire in electrical installations which are used for the extraction of coal by the open method is carried out. The results obtained can be used to improve devices for ensuring electrical safety in the coal industry.

Ключевые слова:
уголь, разрез, карьер, шахта, экскаватор, травма, нулевой травматизм, электротравма, электрический ток, средства защиты, защитное заземление, автоматический контроль, напряжение шага, напряжение прикосновения, сопротивление защитного заземления, заземляющие проводники.

Оценивается динамика развития угледобычи в мире и Российской Федерации, анализируется травматизм при добыче угля. Предметом исследования является угольная отрасль Российской Федерации. Цель исследования – выявить возможные пути повышения безопасности персонала, работающего в угольной отрасли Российской Федерации. Задачи исследования: выявить перспективные направления развития угольной отрасли; провести анализ травматизма в угольной отрасли Российской Федерации; провести сравнительный анализ уровня безопасности при добыче угля в Российской Федерации и других промышленно развитых странах мира; выявить основные причины травматизма в угольной отрасли Российской Федерации; провести анализ имеющихся средств защиты персонала угольной отрасли Российской Федерации от электрического тока и выявить возможности их совершенствования. Методы исследования: анализ статистической информации о добыче угля в Российской Федерации и в мире; патентный поиск устройств, обеспечивающих защиту работников угольной отрасли от воздействия электрического тока.

В статье отмечается, что уровень травматизма при подземной добыче угля в Российской Федерации существенно выше, чем при добыче угля в угольных разрезах. Отмечено, что объемы подземной добычи угля в Российской Федерации за последние годы почти не изменяются, а объемы добычи угля открытым способом растут. Выявлены основные причины травматизма в угольной отрасли Российской Федерации, подробно рассмотрены случаи электротравматизма, проанализированы основные технические средства, обеспечивающие защиту человека от воздействия электрического тока при добыче угля в угольных разрезах. Проведен патентный поиск существующих устройств контроля непрерывности заземляющего провода в электроустановках, которые используются для добычи угля открытым способом. Полученные результаты могут быть использованы для совершенствования устройств обеспечения электробезопасности в угольной отрасли.

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Introduction

The share of coal in world energy is very high (Fig. 1) [1], which is caused by increasing demand for electricity, first af all in China, which is the largest importer of coal. Coal consumption in the world in 2015 was 7.7 billion tons (63.9 % against the level of 2000), but compared with 2014 decreased by 2.7 %. Asia is the main region of the world for coal consumption – 69 %, the countries of the former USSR in fourth place – 4.9 % of global consumption [2]. Coal remains the most economical fuel in a number of countries. For example, according to official data of the Institute of Energy Economics of Japan, coal in 2006 was the most effective type of fuel for electricity generation. On average, the price for coal was 1.15 yen per 1000 kcal compared to 3.29 yen using liquefied natural gas and 4.49 yen for burning fuel oil [3]. It should be noted that China is the leader in terms of coal mining in the world (Fig. 2) [4].

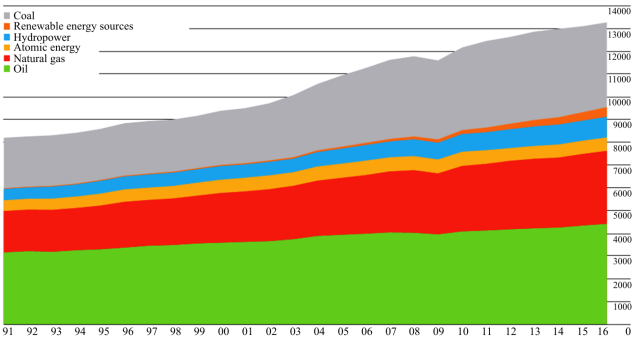

Fig. 1. Dynamics of world energy consumption, million tons of oil equivalent, from 1991 to 2016

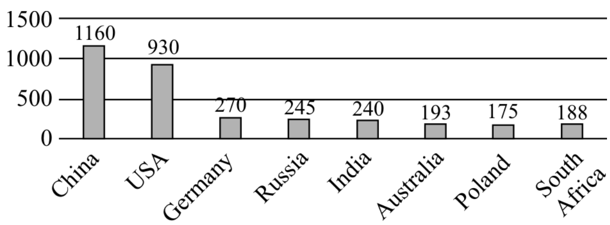

Fig. 2. Coal production in the world, million tons/year

Despite the rapid development of alternative energy, its share in the overall energy balance remains insignificant, the basic share of electricity humanity receives from the use of traditional energy sources: oil, gas, coal [1].

Coal is mined in different regions of the world. Countries of Latin America are the exception, whose share in world coal mining is extremely low. The world's largest coal basins are Appalachian (USA), Ruhr (Germany), Upper Silesian (Poland), Donetsk (Ukraine), Kuznetsk and Pechora (Russia), Karaganda (Kazakhstan), Fushun (China) [4].

Statistical data on injuries in coal industry

Coal extraction in our country and all over the world is accompanied by considerable injuries. The Fig. 3 shows the dynamics of the level of fatal injuries in coal mining in Russia, China, United States and Ukraine [5].

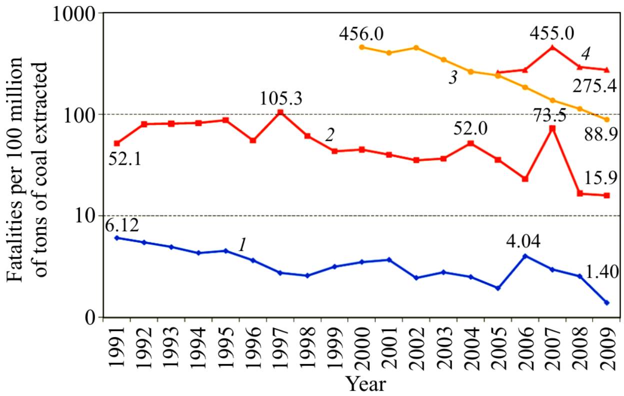

Fig. 3. Dynamics of the level of fatalities in coal mining in the United States (*1*), Russia (*2*), China (*3*) and Ukraine (*4*)

Considering the issues of strategic planning at the coal enterprises of the Russian Federation, it should be noted that recently a number of leading organizations are implementing corporate programs that are close to the idea of "zero injurues" programs. For example, United Coal Company Yuzhkuzbassugol OJSC which is a part of Evraz, aims to "zero fatal accidents and serious injuries." The company saw a quarterly decrease in injuries [6].

In order to reduce the number of accidents in the European Union, since the beginning of the 21st century, programs for "zero injuries" have been actively implemented. The results of the successful implementation of corporate "zero injuries" programs at the EU's are given in [7-13]. The difficulties of rapid and successful implementation of programs in coal industry organizations can indirectly be evidenced by the data of the European Union's statistical service (Eurostat) on accidents in the organizations engaged in the extraction of hard and brown coal (Table 1) [6].

A high level of injuries stimulates researchers to develop new technical means and organizational measures aimed at improving safety in the coal mining process. One of the most promising technical measures is the closure of problem mines. It should be noted that the British government abandoned the underground method of coal mining in 2015. Germany also plans to abandon the underground coal mining in the first half of the XXI century. The Chinese government economically stimulates the closure of problem mines. In our country over the past 25 years several dozens of mines have been closed. Thus, it can be concluded that the global trend consists in the gradual abandonment of coal mining in mines and increase in the share of coal produced by the open-pit method.

Table 1

The dynamics of the number of accidents and fatal accidents in coal mining organizations in the European Union

Country	Year									
	2009		2010		2011		2012		2013	
	accident	fatal accident	accident	fatal accident	accident	fatal accident	accident	fatal accident	accident	fatal accident
Spain	2624	2	256	1	1798	6	1690	1	1372	6
Germany	558	0	520	0	430	1	272	2	297	1
Slovakia	7	0	0	0	1	0	0	0	203	1
Great Brttan	290	3	224	1	282	6	271	0	157	0
Germany	281	4	241	1	182	7	159	3	111	0
Slovenia	117	0	115	0	78	0	110	0	89	0
Hungary	2	0	3	0	2	0	1	0	84	0
Bulgaria	61	3	62	1	68	1	59	1	63	7
Italy	42	0	45	0	25	0	39	0	34	0
Finland	0	0	0	0	18	0	0	0	32	0
Norway	128	0	28	0	140	0	100	0	24	2
Czech Republic	543	1	449	2	516	7	17	5	0	0
Poland	2266	36	2201	15	1930	18	1766	16	1571	8

In 2016, coal mining in Russia was carried out in 58 coal mines and 258 sections, with 20 of the most productive coal mines producing 60 % of coal mined underground, and 20 open-pit mines – up to 55 % [14]. As can be seen from the Fig. 4, the share of coal produced by the open method tends to increase [15-23].

In 2015, the main types of accidents in coal mining, as in previous years, are as follows: the impact of machinery and mechanisms (21.7 % of the total number of injuries received, 28.1 % of all deaths); falling objects, equipment (11.5 % of total injuries, 3.1 % of the measure); the victim's fall from height (11.0 % of total injuries, 6.3 % of deaths); collapses and collapse of rocks (11.0 % of total injuries, 21.9 % of deaths); incidents on ground transport (10.7 % of total injuries, 21.9 % of deaths) [14].

The most frequent organizational causes of injuries in 2015, as in previous years were unsatisfactory work organization, as a result of which 138 people were injured, 12 of them died; violation of labor and production discipline (75 accidents, 3 of them fatal); unsatisfactory content of jobs (51 cases, 1 deaths); violation of safety requirements for the operation of vehicles (49 cases, 5 deaths); violation of the technological process (35 cases, 2 deaths) [14].

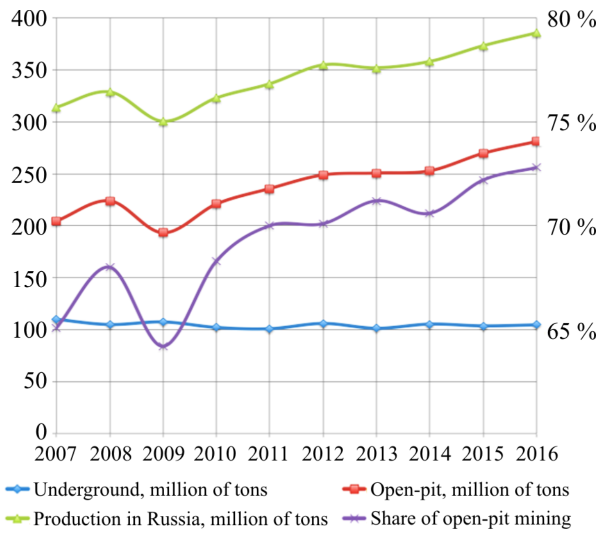

Fig. 4. Volumes of coal mining in the Russian Federation in 2007-2016

The number of injured for technical reasons in 2015 decreased compared to 2014: when operating faulty machines, machinery, equipment – from 14 to 9 people (1.6 times); due to imperfections in the technological process – from 11 to 5 people (2.2 times); due to unsatisfactory technical condition of buildings, structures, territory – from 31 to 14 people (2.2 times). The number of workers injured due to design flaws, imperfections, insufficient reliability of machinery, machinery, equipment increased (from 7 to 11) [14].

In 2015 there were no injuries caused by explosions, gas flares and coal dust, as well as flooding and water breakthroughs [14].

Statistical data on the dynamics of electric shock to employees of the Russian coal industry, collected by us, are presented in Table 2.

Table 2

Dynamics of electrical injury in the Russian coal industry

Reporting year	Total accidents	Including fatal accidents	Total accidents, including due to non-use of collective protection equipment	Including fatal accidents due to the non-use of means of collective protection
2011	11	2	2	1
2012	20	6	6	2
2013	12	6	5	2
2014	17	6	4	2
2015	9	1	4	1

As can be seen from the Table 2, the number of electric damage in the coal industry is relatively small, but up to half of them end with the death of the victim. Relatively large proportion of fatal accidents caused by non-use of means of collective protection. As can be seen from Table 2, the number of electric damage in the coal industry is relatively small, but up to half of them end with the death of the victim. Relatively large proportion of fatal accidents caused by non-use of means of collective protection.

Some cases of electric damage in more detail are considered next.

The electrician checked the voltage of the alternating current panel of the blower motors of the main drives on the ESh-10/70 excavator using APPA-A3D electric measurement clamps. In this case, a short two-phase fault occurred between the current-carrying contacts of the terminal block through the test leads and the insulated surface of the terminal block. An electric arc has arisen. The worker received a thermal burn of the skin of the hands from the effect of electic arc.

When removing the power cable SBG-6-3*70 in RP 6kV No. 126 without checking the presence of voltage by means of an indicator, a victim touched the 6-kV power line with a hand, resulting in an electric injury incompatible with life.

When preparing a workstation to eliminate cable damage in ZRU-6kv p/st 14 35/6 kV, the electrician was under tension. The accident was classified as severe.

During the troubleshooting on the panel of the ECG-4U No. 2 excavator in the mountain section Razrez Yerkovetskiy SP, a short circuit occurred between the outcoming feed flexible connections of the feeder circuit automatic switch breaker and automatic switcher of the lubrication system of the drive gears of the turn actuator. As a result of a short circuit, the electrician received a thermal burn of the face, eyes, neck, chest, forearms, hands.

The reduction in injury rates is accompanied by an ongoing decline in the number of employed in the industry. The most accidential is the underground mining method. Durint the period of interest from 51.6 (2015) to 62.7 % (2010) of cases of general injuries occurred. At the same time, at least 40 % of the cases of the general and 36 % of the fatal injuries occur in the course of cleaning and preparatory works [14].

There are statistical data on the dynamics of injuries in the Russian Federation by main categories of workers presents in the Table 3 [14]. From the Table 3 it can be seen that the total number of accidents in the conduct of underground work is several times greater than in sections, the least amount of injuries occur in the concentrators. Statistical data allow us to confirm the thesis advanced above about the greater danger of work in the mine than in the section. The data in the Fig. 4 and Table 2 indicate that an increase in the extraction of coal by the open method in 2015 by 10 % has led to an increase in the number of accidents by more than 30 %, and the number of fatal non-communicable cases has almost doubled. At the same time, the total number of fatal injuries in coal mining decreased. It can be assumed that the further closure of the coal mines in the Russian Federation and transition to coal mining in the sections will undoubtedly lead to a reduction in the level of fatal injuries in coal industry, but the number of injuries, including fatalities, in coal mines in our country may increase several fold.

Table 3

Dynamics of injuries by main categories of workers

Year, injuries		Total	Employees	Engineering staff		Workers			
				Total	Underground	Total	Underground	On sections	At processing plants
2010*	Total, including	1308	5	107	86	1176	868	135	62
	fatally injured	144	0	13	9	111	91	13	4
	disabled	101	0	11	9	90	70	12	1
2011**	Total, including	948	7	77	52	864	576	125	47
	fatally injured	58	0	5	3	53	33	17	1
	disabled	83	0	13	10	70	54	10	0
2012	Total, including	977	6	101	78	870	609	111	52
	fatally injured	54	0	5	5	49	26	15	3
	disabled	85	1	15	9	69	53	8	3
2013	Total, including	808	4	82	62	722	488	98	44
	fatally injured	74	1	8	6	65	51	9	3
	disabled	74	1	14	10	59	49	6	0
2014	Total, including	565	2	63	40	500	331	91	32
	fatally injured	35	0	6	3	29	15	8	3
	disabled	68	0	12	9	56	41	7	3
2015	Total, including	637	5	61	42	571	345	125	43
	fatally injured	32	1	4	1	27	9	15	3
	disabled	60	1	7	5	52	44	4	2

Note: * There were 20 employees of the militarized mine-rescue unit dead during the elimination of the accident at the Raspadskaya mine in 2010. ** There were 9 employees of contracting company dead during the mining in 2011.

Analysis of possible ways to increase electrical safety of coal industry employees

Given above allows to put forward a hypothesis about the need to improve organizational arrangements and technical means to protect people while working in coal mines.

Work in coal mines is carried out with help of machines and units using powerful electric motors. In order to ensure the steady power supply of these devices complex power supply schemes are used. There are several specific features of operation of electrical units in coal mines. The length and branching of the electrical network (depth of the Krasnogorskiy section, for example, reaches 200 m) is one of them [14]. Another one is the high probability of mechanical impact on the insulation of cables when moving machines and mechanisms and carrying out blasting operations. Increasing the depth of quarries adversely affects the sanitary and hygienic working conditions and technical and economic indicators of companies. Intensification of mining operations, increase in depth of quarries and consequent weakening of the efficiency of natural ventilation lead to contamination of the atmosphere by dust and toxic gases. At the same time, there is a stable layer of dust formed on the insulator surface during the high dust content in the air. During rain or snow, the dust layer moistens and insulation resistance drops sharply. Decrease in the insulation resistance can lead to both equipment failures and electrical personnel injuries. In order to protect a person from electrical current during coal mining by the open-pit method the control of the state of insulation of electrical units, protective "shutdown" and protective grounding are used.

In order to prevent the danger of electric shock due to the voltage transition to the structural parts of electrical equipment and installations, protective grounding is performed.

The person being near the grounded equipment, having a short to a body and touching the body will be affected only by a part of the total voltage under which the damaged equipment is located relative to the earth.

The grounding device includes a rod and conductors connected to it at least in two points. A rod provides the required resistance to current flow, and conductors allow the connection of equipment to be grounded.

The general grounding device of the quarry consists of central and local grounding devices. The central grounding devices are located on the main step-down substation of the quarry or separately on its board. Local grounding devices are made in the form of groundings constructed at mobile emergency points, mobile complete transformer substations with voltage of 6-10/0.4 kW and at other units [24].

There are contour and remote grounding devices. Contour grounding devices are used during the open-pit mining in down-site substations located on the surface. The principle of operation of such devices is to reduce the contact stress and pitch due to equipotential bonding. Remote grounding devices are used directly in quarries [24]. They are characterized by a significant distance from the electrical equipment, resulting in a drop in contact voltage on the resistance to current flowing on the grounding device. This feature limits the scope of application of the remote grounding device to networks with single-phase ground fault currents no more than 500 A. Safety in this case is ensured by a low resistance to the current flow of the grounding device. The resistance of a common grounding device must not exceed 4 Ω·m [25]. That includes the resistance of the central grounding and resistance of grounding conductors.

For stationar units as the main grounding wires laid on the supports of overhead power transmission lines in a quarry, it is recommended to use steel single-wire and steel-aluminum wires as well as aluminum and steel-aluminum wires for mobile units. The main grounding wires should have steel single-wire with diameter of at least 6 mm. The diameter of steel multiwire, steel-aluminum and aluminum wires should have a cross section of at least 35 mm^2 [24].

The practice of protective grounding in quarry conditions showed that the lack of central grounding could cause damage of a grounding network, especially of grounding conductor of a flexible cable. Breakdown of the main conductor can be dangerous, as it can disrupt the grounding of a group of mobile quarry electrical installations if they have poor self-grounding (with low ground conductivity).

In order to increase electrical safety continuous automatic monitoring of the integrity of the grounding network is required, especially in quarries with a small number of excavators and with low ground conductivity. It is recommended in a section 10 of [25] to automatic control devices to check the continuity of the grounding circuit in the networks of coal cuts.

Known devices for monitoring the continuity of the grounding network are characterized by several features. The first of them are the type of the applied operational voltage source and type of current. In connection with given above external sources of constant, rectified (pulsating) and alternating current (low or high frequency), and sources of pulsed operational current are used. The supply network is used as a source of operational current or component of the zero sequence of the mains voltage [24].

The following classification indicator refers to the way in which the return channel of the monitoring circuit (return wire) is executed. The role of the second wire is performed by an additional lead wire or in a particular case shielding braids of a flexible cable; earth in case of sufficiently high ground conductivity; a set of wires of a network feeding a mobile electrical unit [24].

Depending on the control scale, the known devices can be subdivided into rod or flexible cable integrity monitoring devices, grounding continuity monitoring devices and systems, controlling the parameters of the grounding devices in a quarry.

The devices for monitoring the integrity of the rod or flexible cable cover only a part of the grounding circuit in the area from the mobile emergency point (EP) to the excavator, grounding conductor of a flexible supply cable. That is caused by the fact that the cables have rather high damageability. It is assumed that the ground resistance for the EP does not exceed 4 Ω [24].

Devices that control the continuity of the grounding circuit monitor the integrity of the grounding all the way from the central grounding switch to mobile electrical unit as well as the integrity of the grounding conductor of the cable. At the same time the devices monitor the grounding continuity of grounding lines (cables) of the quarry and branches from the mains to the EP. In some cases transitional resistance of the local grounding contacts between the ground and the equipment support surface come into the monitoring zone. The necessity to control the integrity of the main grounding cable is caused by the heavy operating conditions associated with frequent overhauling of networks and blasting operations in quarries [24].

The overview of existing today devices for monitoring the integrity of the grounding network is given next. "Kemerovo Experimental Plant of Security Equipment" is the main producer of products that provide security at coal companies and companies of other branches of the extractive industry.

In order to ensure the protection of emplyees when working in sections from electric current the experimental plant manufactures the device for monitoring the grounding of career electrical units (CEU) [26]. The device is designed to monitor the integrity of the grounding circuit of career electrical units and improve safety in open-pit mining. It is used when feeding mobile mining machines with flexible cable with auxiliary control veins. The CEU is installed from the inside of the emergency room and serves to monitor the integrity of the grounding conductor of a flexible cable that feeds mobile mining machines and electrical units on open-pit mines. The device monitors the circuit segment from the emergency location to the electrical unit (mining machines). In the event of a break or increase in the electrical resistance of the grounding circuit, as well as in the unauthorized opening of the protective enclosures of electrical equipment, the high voltage switch of the switching point is disconnected. At the same time, the warning light comes on. The device has self-monitoring of serviceability when the auxiliary conductor is grounded, breakdown of a circuit and transformer windings, breakdown of a diode. The products are manufactured in accordance with the requirements [27]. The permission of the Federal Service for Ecological, Technological and Nuclear Supervision is granted.

The experimental plant also manufactures an automatic grounding circuit integrity monitoring device [28]. It is intended for automated control of integrity of a grounding circuit of mobile mining machines on coal and other sections and quarries. The device retains its technical characteristics at ambient temperature from –40 to +45 ºС, relative air humidity up to 80 % at a temperature 25 ºС and dustiness of air up to 250 mg/m³. The device is installed on the outer side panel of the control section of the control point on an open-pit mine and serves to check the integrity of the ground wire of the high-voltage line. It controls the section of the power line circuit up to the emergency point. The products are manufactured in accordance with the requirements [27]. The permission of the Federal Service for Ecological, Technological and Nuclear Supervision is granted.

Patent search for tools to control the integrity of grounding circuit for mining industry of the Russian Federation

The analysis of documents showed that the maximum number of copyright certificates and patents for devices for monitoring the integrity of the grounding circuit of mobile mining machines was obtained in the 80-90's of XX century. Today there are no valid patents for devices for monitoring the integrity of the grounding circuit for the mining industry of the Russian Federation.

According to the patent search there is a patent found for a utility model "Device for monitoring the grounding of quarry electrical units" [29] due to such a device, as it was explained above, is now widely used to protect workers of coal mines from electricity. "The utility model belongs to the field of electrical engineering, in particular to power supply systems, and is designed for periodic monitoring of earth resistance of quarry electrical units in open pit mining. The technical result of the utility model is to increase the efficiency and provide the ability to control the resistance to grounding of quarry electric installations in open-pit operations in places with a high specific resistivity of rocks and presence of electrical potentials (jams) on grounding devices". The patent for that utility model was over in 2012. An analysis of the patent for the utility model "Device for monitoring the grounding of mining machines" is performed [30]. "The utility model refers to the field of electrical engineering, in particular to power supply systems in open-pit mining and can be used in systems for monitoring the integrity of the grounding circuits of mobile mining machines, for example, excavators in coal mines and other mining companies on the surface. The technical result of the utility model is to improve the effectiveness of monitoring the integrity of the grounding circuit by eliminating emergency shutdowns of mining machines during their operation in the event of faults in the grounding circuit. The patent for that utility model was over in 2015.

It can be concluded that today there is no patent protection of ground control devices for the mining industry of the Russian Federation, which are in serial production. Researchers do not offer new solutions that can provide effective protection when using modern electronic microprocessor technology, the capabilities of which significantly exceed not only the capabilities of electronics of 80-90's XX century but electronics of early XXI century.

Conclusions

According to statistical data, the volumes of coal mined in our country and in the world as a whole are growing every year. The growth in coal production is accompanied by an increase in injuries both in the Russian Federation and in other countries. The volume of coal extracted from mines of the Russian Federation for the past five years is changed slightly, the growth is provided by increased production in coal mines. Increase in the extraction of coal by the open-pit method can lead to an increase in electrical injury. That is caused by the specifics of the operation of mains, which provide electric power to mining machines. Reduction of electrical injury during coal mining in quarries is possible with the provision of high reliability of protective grounding. In order to achieve the goal, automatic devices for monitoring the integrity of the ground circuit of mining machines in coal quarries are widely used. The patent search revealed a certain stagnation in development and implementation of such devices in the Russian Federation on the latest microprocessor base. There are no existing patents for grounding continuity monitoring devices. The devices we analyzed were patented more than 10 years ago. All of the given above confirms the need to develop an automatic device for monitoring the integrity of the grounding circuit of mobile mining machines in the coal sections of the Russian Federation using the most advanced electronic components, which will improve the reliability of protective grounding on coal quarries.

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