KAZAKH NATIONAL RESEARCH TECHNICAL UNIVERSITY NAMED AFTER K.I. SATBAYEV

Institute K.Turusov institute of geology, Oil and Mining

Department of Mining

Salykbayev Arys Kuanyshevich

«Improvement of blast-hole breaking, given the fracturing of the rock mass»

MASTER'S DISSERTATION

Specialization 6M070700 – «Mining»

Almaty 2021

MINISTRY OF SCIENCE AND EDUCATION OF THE REPUBLIC OF KAZAKHSTAN
K.I. Kazakh National Technical Research University named after Satpayev
K. Turysov Institute of Geology, Oil and Mining
Department of Mining

UDC 622.235 : 622.268 On the right of the manuscript

Salykbayev Arys Kuanyshevich

Prepared for a master's degree

MASTER'S DISSERTATION

Title of the dissertation «Improvement of blast-hole breaking, given the fracturing of the rock mass»

Direction of preparation 6M070700 – «Mining»

Research supervisor:
Candidate of technical sciences,
senior lecturer,
___________ D.K. Akhmetkanov
«10» 06 2021y.

Reviewer:
International Educational Corporation,
Deputy Dean of the Faculty of General Construction of the Kazakh Academy of Architecture and Civil Engineering
_________ E.A. Elzhanov
«14» 06 2021

Подпись _______ заверяю HR департамент _______ «___» _______ 20__
HR - ДЕПАРТАМЕНТІ
HR - ДЕПАРТАМЕНТ
HR - DEPARTMENT

Norm observer
Candidate of technical sciences,
senior lecturer,
______________ D.K. Akhmetkanov
«10» 06 2021.

SENT TO PROTECTION
Head of the «Mining» Department
Satbayev University,
Doctor of Technical Sciences,
Professor
__________ S.K. Moldobayev
«15» 06 2021.

Алматы 2021

MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

K.I. Kazakh National Technical Research University named after Satpayev

O.A. Baikonurov Mining and Metallurgical Institute

Department of Mining

6M070700 – "Mining"

I APPROVE
Head of the «Mining» Department
Satbayev University,
Doctor of Technical Sciences,
Professor
___________ S.K. Moldobayev
«15» 06 2021.

TASKS
for master's dissertation

Master student *Salykbayev Arys Kuanyshevich*
Subject: «Improvement of blast-hole breaking, given the fracturing of the rock mass».
Approved by the order of the Rector of the University dated February 28, 2020 №1784-m.
The deadline for submission of the completed dissertation is "08" July 2020.
Initial submissions of the master's dissertation: *it is necessary to study the mining geological, hydrogeological, mining technical conditions of the mine area and the physical and mechanical properties, stress-strain conditions of the underground mining masses; Expertise and analysis of the field development schemes for the development of the deposit, the conditions of the mine, which has been built so far for complex, preparatory and ore mining, as well as future construction projects and schemes (on the horizons); to do; In addition, it is necessary to analyze the technology of mining and methods of fixing mining, used in other experiments in different geological conditions; it is necessary to identify the fastening structures and factors affecting the quality and efficiency;*
The list of issues considered in the master's dissertation:
1. Analysis of existing and promising methods and techniques of drilling operations in the conditions of JSC "Apatit

2. Development of mechanical and mathematical models of description of processes in percussion systems of drilling machines.
3. Development of methods for calculating the parameters of the elements of the shock system "piston-paint-rod" to achieve the growth of the impact stroke.
Recommended basic literature:

1. A.A. № 1398502. Underwater drilling rig / V.Y. Kipovsky, S.O. Kochetov D.A. Jungmeister -1988.
2. A.A. № 140228. M.K. Drilling device. E21C3 / 04, BI N-7, 1989. authors: A.A. Manin and V.I. Chiriev.
3. A.A. № 713969 Device for the destruction of mountain prod. M. Cl E02
4. F9/22, BI No. 5, 1980, authors: V.G. Kuznetsov, etc.A/c № 857415 МПК E21B4/06. Method of destruction of rocks shock impulses. БИ № 31, 1981. г.
5. A.A. № 337505 (CCCP). A device for thermal drilling of mineral media under water, authors: A.B. Brichkin, A.N. Grenbach, V.V. Povetkin 1972.
6. A.A. № №1153052. Impact device for destruction rocks. A.N.Moskalev A.I. Stepanyuk, A.A. Galyas Trokhimets. M, CL. E 21 C3/00. 1985y.
7. E.V. Aleksandrov, V.B Sokolinsky . Applied theory and calculations shock systems."Science", 1969.

Preparation of master's dissertation

SCHEDULE

№	Name of the department, list of issues to be considered	Terms of presentation to supervisors and consultants	Warning
1	Study of geological, hydrogeological, geomechanical and mining technical conditions of the Kirov field, mine area	14.02.2021y.	
2	The choice of parameters of fastenings and the study of its structure, based on the choice of the type of fasteners and the use of effective fasteners on the excavation, which is the object of research. Identify factors that affect the quality and effectiveness of fasteners. Study of the method of fastening.	04.03.2021y.	
3	Feasibility study of the adopted types of fastenings	15.04.2021y.	
4	Safety measures during the passage and fastening of underground mining	13.05.2021y.	

Advisers to these master's dissertation departments and signatures of the controller

Name of sections	Consultants name, patronymic, surname (academic degree, title)	The term of	Signature
Geomechanical department	Scientific adviser D.K Akhmetkanov, senior lecturer, candidate of technical sciences	14.02.2021y.	
General section	Scientific adviser D.K Akhmetkanov, senior lecturer, candidate of technical sciences	04.03.2021y.	
Special section	Scientific adviser D.K Akhmetkanov, senior lecturer, candidate of technical sciences	15.04.2021y.	
Department of safety rules during excavation and approval	Scientific adviser D.K Ahkmetkanov, senior lecturer, candidate of technical sciences	13.05.2021y.	
Normocontroller		13.05.2021y.	

Scientific adviser D.K Ahmetkanov _ ___D.K Akhmetkanov, senior lecturer

The student who received the task ____________ A.K. Salykbayev
Date «14» 06 2021y.

АҢДАТПА

Диссертацияларда бұрғылау құралының бұрғылау жылдамдығы мен беріктігін арттыру үшін пневматикалық перфораторлар мен ұңғымалы пневматикалық балғалардың жетілдірілген механикалық-математикалық модельдеріне сәйкес олардың негізгі параметрлерін оңтайландырумен жаңартылған конструкцияларын жасау қарастырылды. «Апатит» АҚ жағдайында бұрғылау жұмыстарын жүргізудің қолданыстағы және перспективалық әдістері мен техникалық құралдары талданды. Бұрғылау машиналарының соққы жүйелеріндегі процестерді сипаттаудың механикалық-математикалық модельдерін жасау. Соққы тиімділігінің артуына қол жеткізу үшін «поршеньді-соққылы-штангалы» соққы жүйелерінің элементтерінің параметрлерін есептеу әдістемесін әзірлеу. Жаңартылған тау-кен бұрғылауыштарының және DTH балғаларының орналасу сызбаларын, олардың құрылымдары мен қолдану салаларын негіздеу.

Теориялық есептеу және сандық модельдеу терең ұңғымаларды алдын ала жару кезінде ұңғымалар арасындағы тау жыныстарының сыну механизмін, динамикалық және статикалық жүктемелердің синергетикалық әрекеті әсерінен жарықшақтардың дамуын, сондай-ақ жарықшақтар қозғалысының механизмін талдау үшін жүргізілді. бос ұңғымалардағы ығысу кернеулерінің концентрациясымен анықталады.

АННОТАЦИЯ

В диссертаций рассмотрена разработка модернизированных конструкций пневмоперфораторов и погружных пневмоударников с оптимизацией их основных параметров по разработанным механико-математическим моделям для повышения скорости бурения и стойкости бурового инструмента. Были анализированы существующих и перспективных способы и технические средства ведения буровых работ в условиях ОАО "Апатит". Разработка механико-математических моделей описания процессов в ударных системах буровых машин. Разработка методики расчета параметров элементов ударных систем "поршень-боек-штанга" для достижения роста КПД удара. Обоснование компоновочных схем модернизированных перфораторов и погружных пневмоударников, их конструкций и областей применения.

Теоретический расчет и численное моделирование были выполнены для анализа механизма трещинообразования горной породы между скважинами при предварительном взрывании глубоких скважин, развития трещин под действием синергетического действия динамических и статических нагрузок, а также механизма движения трещин, определяемого концентрацией касательных напряжений в пустых скважинах.

ANNOTATION

The dissertations considered the development of modernized designs of pneumatic perforators and downhole pneumatic hammers with the optimization of their main parameters according to the developed mechanical and mathematical models to increase the drilling speed and durability of the drilling tool. The existing and prospective methods and technical means of conducting drilling operations in the conditions of JSC "Apatit" were analyzed. Development of mechanical and mathematical models for describing processes in percussion systems of drilling machines. Development of a methodology for calculating the parameters of the elements of the "piston-striker-rod" shock systems to achieve an increase in the impact efficiency Substantiation of the layout diagrams of modernized rock drills and DTH hammers, their designs and areas of application.

Theoretical calculation and numerical modeling were carried out to analyze the mechanism of rock fracturing between wells during preliminary blasting of deep wells, the development of cracks under the action of the synergistic action of dynamic and static loads, as well as the mechanism of crack motion, determined by the concentration of shear stresses in empty wells.

CONTENT

INTRODUCTION

Relevance. The development of mining engineering in the USSR and the Russian Federation was aimed at creating a diverse and efficient domestic drilling equipment with the required production volumes; domestic modernized pneumatic perforators with improved characteristics were created (NIPIrudmash, A.A. Skochinsky IGD), hydraulic perforators that are not inferior to their foreign counterparts (Gipronickel), the plans were to create the latest drilling rigs and mining rigs. The peculiarities of the 90s dramatically changed the situation - a significant share of mining engineering plants ended up abroad, R&D programs were curtailed, research and design institutes are not working efficiently enough. In mining operations, it is becoming increasingly difficult to maintain existing equipment in good working order. However, while increasing production volumes in recent years, Apatit OJSC has been forced to find opportunities to buy the best samples of drilling equipment, both domestic and foreign - Solo rigs and Minimatik rigs by Tamrock, the price of which is significantly higher than the prices of domestic counterparts. This raises questions about expanding the use of domestic samples of drilling equipment. The exploited domestic drilling equipment is largely worn out and outdated. The introduction of new types of drilling equipment into production is rare. Therefore, it is necessary to conduct research to create new drilling technologies and samples of domestic drilling equipment, the effectiveness of which is theoretically substantiated and experimentally confirmed. So, for example, at present, the improvement of the designs of portable perforators (1111-54, 1Sh-63, etc.), the SBSh-250 rig will increase the drilling productivity in comparison with the samples of the traditional layout, which will make them competitive with Western samples when drilling apatite and other ores occurring together with them.

It is advisable to substantiate the basic models of drilling equipment in the conditions of JSC "Apatite".

As a drilling machine, it is advisable to use modernized rock drills, which have an increased drilling speed and tool life, an expanded field of application and based on standard assemblies and parts, which will significantly reduce the cost of drilling and the number of drillers.

The work is based on research: Alimova O.D., Asatura K.G., Zagrivnogo E.A., Ivanova K.I., Kantovich L.I., Kolomiytsova M.D., Krasnikova Yu.D., Nagaeva R.F., Poderny R Yu., Sokolinsky V.B., Khazanovich G.Sh., Ushakova L.S. and etc.

The purpose of the work is the development of modernized designs of pneumatic perforators and downhole pneumatic hammers with the optimization of their main parameters according to the developed mechanical and mathematical models to increase the drilling speed and durability of the drilling tool.

Work idea: modernization of the design schemes of perforators and submersible pneumatic hammers, taking into account the increase in the efficiency of impact transmission with the transition to a quasi-plastic impact based on the bounce of a smaller part of the separated projectile and obtaining a rational shape of the shock pulse, which allows for effective destruction of the rock.

Protected scientific positions .

1. It was found that when the ratio of the mass of the striker to the nominal mass of the rod is greater than the sum of the doubled coefficient of recovery of the velocity of the striker and the square of this coefficient, the energy transmitted from the piston to the rod during quasi-plastic impact is exceeded in comparison with a partially elastic systems.
2. In the shock system, in which the piston-striker is divided into a large (piston) and a smaller (firing pin) part, a total shock pulse of adjustable amplitude and duration is formed, consisting of at least three bursts (sub-pulses), the parameters of which are controlled by changing the distance between the rod and briskly.
3. When the shock load of the DTH hammer is damped by installing elastic elements in front of the piston, the force, duration of the impact and the main parameters of which are described by a parametric differential equation, an increase in the drilling speed and resistance of the bit is achieved by adjusting the parameters of the shock pulse.

The main tasks of research:

1. Analysis of existing and prospective methods and technical means of conducting drilling operations in the conditions of JSC "Apatite".
2. Development of mechanical and mathematical models for describing processes in percussion systems of drilling machines.
3. Development of a methodology for calculating the parameters of the elements of the "piston-striker-rod" percussion systems to achieve an increase in the impact efficiency.
4. Обоснование компоновочных схем модернизированных перфораторов и погружных пневмоударников, их конструкций и областей применения.
5. Analysis and experimental research at the stands and in the mine conditions of the main parameters of the structures of the modernized rock drills and submersible hammers for drilling rigs.
6. Development of designs of modernized rock drills and downhole hammers for drilling rigs and determination of their rational parameters using algorithms that take into account the dynamic processes of modernized rock drills and hammers.

Research methods

To solve the set tasks, a complex research method was chosen, including methods of mathematical analysis, the results of which were compared (corrected) based on the analysis and generalization of data obtained in the course of laboratory and industrial experiments. In this case, the following methods were used: analytical (review, generalization and analysis of previously performed scientific research); mathematical modeling (optimization of parameters of drilling machines);

experimental (physical experiments on stands and pilot industrial research to improve the design of drilling machines).

Scientific novelty consists in the definition of new functional and parametric dependencies, obtained on the basis of the stereomechanical theory of impact, allowing to determine the ratio of the masses of the separated parts of the striker and providing an increase in the efficiency of transmission of impact, substantiation of the layout diagrams of perforators and pneumatic hammers based on the study of mechanical and mathematical models describing their functioning.

Credibility scientific provisions, conclusions and recommendations contained in the dissertation are confirmed by the use of proven mathematical methods, fundamental provisions on the dynamics of machines, the adequacy of the behavior of the calculated dynamic models of drilling machines to the objects of study, satisfactory convergence of the results of analytical and experimental studies on the stands and in mine conditions, as well as sufficient the volume of experimental studies in the conditions of the Kirov and Vostochny mines of JSC "Apatit".

Practical value. The developed methods for calculating shock systems make it possible to more reliably calculate the parameters of double strikers and spring-loaded shock systems. The design of the perforator with a split hammer allows to increase the drilling speed by 20-30%, the DTH hammer based on the proposed new drilling method for SBSh-250 allows increasing the durability of the roller cutter (by 10%) and increasing the drilling speed by 10-15%.

Implementation of work results

Variants of design documentation based on fundamentally new schemes of drilling facilities are used at.

CHAPTER 1. ANALYSIS OF DRILLING MEANS AND METHODOLOGICAL BASIS FOR IMPROVING THE DRILLING WORK PROCESS

1.1. Analysis of the condition of drilling works at ojsc "apatit"

In recent years, JSC "Apatit", including the Kirovsky mine, has been steadily increasing its annual productivity, approaching the planned value. This speaks of the withdrawal of production from the crisis situation, skillful management, selection of reliable partners, suppliers and buyers.

At present, at the underground mines of OJSC Apatit, in order to improve ore mining, the transition to a mining system with sublevel caving with end-face ore output is being carried out, which corresponds to the deteriorating geodynamic conditions of development at the lower horizons.

The adjustment of the feasibility study for the development of OJSC Apatit in the period 2003-5-2020, carried out at OJSC Giproruda, provides for the technical re-equipment of the mine, taking into account the transition to a new development system, i.e. by replacing the outdated fleet of domestic mining equipment with imported equipment.

Capital investments in the expansion and reconstruction of the Kirovsky mine are planned to be made at the expense of two sources of financing - direct investments and the amortization fund of the enterprise. At the same time, capital investments for the purchase of equipment amount to 3.4 billion rubles. (107.6 million dollars), of which more than 20% is provided for the replacement of existing equipment.

The need to replace the main technological equipment is associated with a high degree of wear: about 80% of the existing equipment is worn out beyond the standard period. The created situation obliges already in 2002-5-2003. provide for the costs of replacing almost the entire fleet of worn-out equipment.

In the period 2021-2050. the main processes of the mine are planned to use:

- for the delivery of rock mass - loading and hauling machines of the type TORO-400E, TORO-400D, TORO-150E and dump trucks TORO-35D and TORO-40D;

- for drilling - drilling carriages of the MINIMATIC type and drilling rigs of the SOLO and SIMBA types;

- on workings support and other processes - installations SCALEER, ROBOLT, SPREIMEK, TRANSMIXER, cassette complexes NORMET, UNIVERSAL-5 0-2, etc.

494.7 million rubles are provided for the purchase of equipment. (15.5 million dollars), which by 73.5% will be used in the period 2021-T-2030. Renewal of worn out equipment should be carried out from the depreciation fund of the enterprise.

Analysis of the forecast background and design solutions incorporated in the technical and economic developments for the long-term development of Apatit and, in particular, in the development strategy of the Kirovsky mine, allow us to conclude that the use of imported equipment in mining operations instead of worn-out domestic equipment is unambiguous, the fact that such a program of technical re-equipment requires very significant investments. The use of high-performance mining and tunneling equipment makes it possible to increase production volumes and, accordingly, reduce the cost of production, but it also has quite serious drawbacks, which are as follows.

1. High price of equipment (tens of thousands and hundreds of thousands of dollars per unit).

2. The high cost of spare parts for repair, and, accordingly, significant costs for current and major repairs.

3. Possibility of sinking workings only of large cross-section.

The use of domestic, much cheaper, drilling equipment makes it possible to mine workings of a small cross-section, allows you to organize work through multi-station maintenance of equipment and has a large social effect - it allows you to load domestic mining engineering plants, as well as create new jobs in related industries.

Mechanical engineering and metalworking in Russia account for about 18% of GDP, their annual turnover is more than $ 55 billion. The industry employs more than 8.5 million people. And together with the military-industrial complex, which also produces civil engineering products, the industry makes up at least a quarter of the Russian economy.

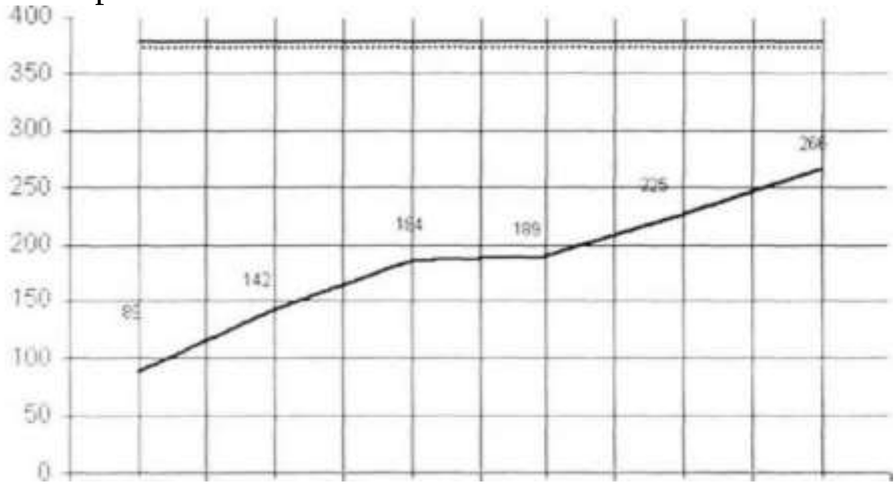
About 90% of Russian machine-building enterprises are corporatized, but the state owns a controlling stake in only 15% of the companies. Mechanical engineering in Russia is focused mainly on the domestic market. The export of the industry is about $ 6 billion per year (of which $ 2.5 billion is the export of military products), or 10-12% of production. Since 1990 the export of Russian mechanical engineering has decreased by 3.5 times, and its structure has also changed - over 10 years, the export of power equipment has grown by 30%. At the same time, up to 30% of Russian imports are products of foreign engineering firms.

Currently, the main manufacturer of mining equipment in the country is the holding company United Machine-Building Plants (Uralmash-Izhora Group), which produces about 70% of drilling equipment, 60% of special steels, over 90% of mining equipment, 78% of metallurgical equipment and about 50% of equipment for nuclear power plants. The process of forming and restructuring the group is not over yet. The holding's activities will gradually focus on several main areas, including the production of equipment for exploration and production of oil and gas, as well as equipment for the mining industry.

The main directions of modification and use of pneumatic drilling tools (perforators) can be determined on the basis of theoretical studies developed jointly with specialists from SPGGI (TU) and SPGU [12, 105]. These areas are: substantiation of the parameters and type of perforators, the shape of the shock pulse and the design of shock systems, depending on the type of rock to be destroyed,

Figure 1.1. The schedule of changes in the productivity of the Kirovsky mine

At present, both domestic pneumatic drilling machines and foreign hydraulic drilling machines are used during drilling and blasting operations at the Kirovsky mine [13]. Figures 1.1-1.5 prove the dynamics of productivity and type of drilling equipment for the period 19964-2001.



1996 1997 1998 1999 2000 plan

--------- Fact, production -.-.-.-. Planned production

Figure 1.1. The schedule of changes in the productivity of the Kirovsky mine

Table 1.1- Drilling equipment for the Kirovsky mine for 2002

№	Equipment identification	Planned number of equipment to fulfill the production volume	Availability of equipment at the beginning of the	quipment to be discarded according to depreciation rates	The stated amount of equipment for 2001	The stated amount of equipment for 2002
1	2	3	4	5	6	9
1	Perforators ПК-60, Б-106	38	38	. 34	20	20
2	Perforators ПТ-48А	62	49	50	30	30
3	Perforators ПП-63В2Л	120	46	46	30	60
4	Perforators ВВД-46	30	30	30	4	10
5	Pneumatic support П-2, П-3	120	-	-	60	60
6	Drilling rigs НКР-100М	70	41	15	10	
7	El engines for machine tools НКР- 100	70	41	15	30	
8	Combine harvester 2КВ1	2	2	2	1	
9	Used "Minimatic ГС-205»	9	9	2	-	
10	Used "SOLO"	4	4	2	-	

Таблица 1.2 - Condition of imported self-propelled equipment

Machine type	Wear rate	Years				
		1997	1998	1999	2000	2001
Minimatic	Less than 100%	0	0	0	3	5
	100% wear	11	9	8	б	б
Soolo	Less than 100%	0	0	2	3	3
	100% wear	3	3	2	1	1

Table 1.3- Self-propelled equipment condition

Machine type		Years				
		1997	1998	1999	2000	2001
Minimatic	Total:	1 I	10	13	12	11
	Total (pcs)	11	9	8	9	11
	Wear less than 100%	0	*0*	0	3	5
	100% wear	1 I	9	8	6	6
Solo	Total (pcs)	3	3	4	4	4
	Wear less than 100%	0	0	*2*	3	3
	100% wear	3	3	*2*	1	1

Table 1.4 -Ore mining dynamics

Years	1996	1997	1998	1999	2000	2001
						план
Total mined	6 825,2	6 921,2	*6* 959,4	7 300,6	7 703,2	7 900,0
incl. self-propelled	1 064,6	1 562,7	1 841,3	2 459,7	2 702,7	2 928.5

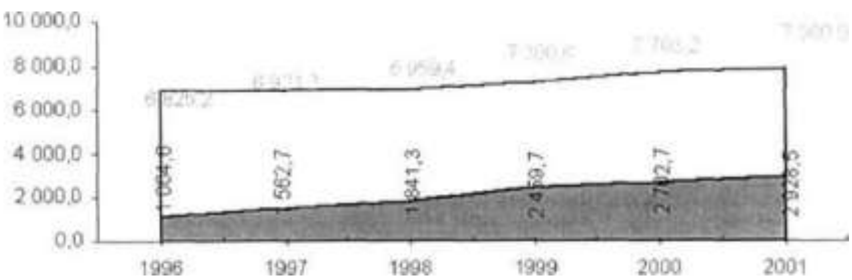


Table 1.5 - Main technical and economic indicators of production "

Ore mining						
Years	19%	1997	1998	1999	2000	2001 план
Total mined	6 825.2	6 921,3	6 959,4	7 300,6	7 703,2	7 900,0
Including self-propelled vehicles	1 064,6	1 562,7	1 841,3	2 459,7	2 702,7	2 928,5
Number of cars	12	11	10	13	12	11
Fact, knowledge	89	142	184	189	225	266
Planned production	378	378	378	378	378	378

Table 1.6 -Main technical and economic indicators of penetration

Penetration						
Years	1996	1997	1998	1999	2000	2001 план
Total passed	14 878	16412	17 546	17 800	18 341	19 536
incl. Minimaggik	3 918	4 554	5 895	6 651	7 885	8 765

Driving with Minnmatic drilling carriages

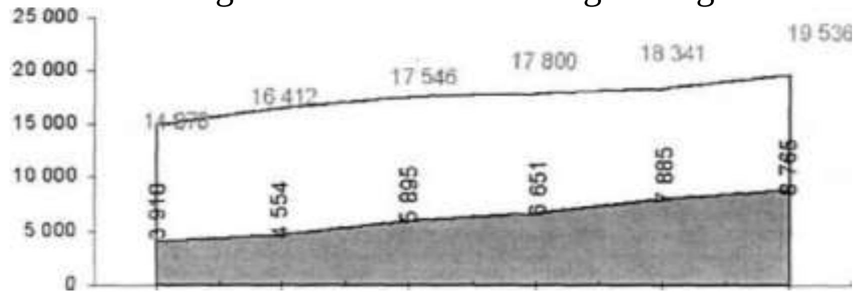
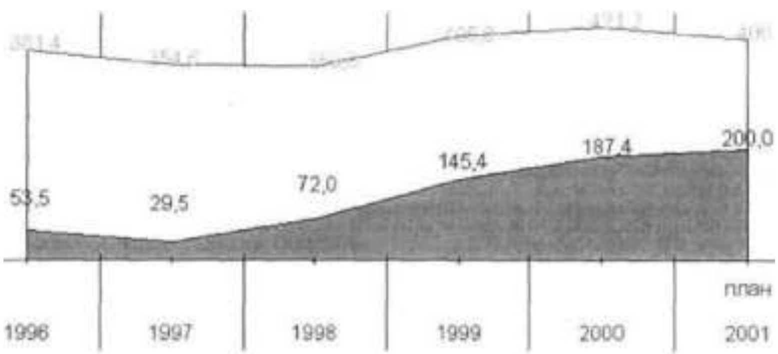


Table 1.7- Well drilling dynamics

Deep hole drilling						
Years	1996	1997	1998	1999	2000	2001 план
Wells drilled in total	381,4	354,6	350,8	405,6	421,2	400,0
incl. SOLO	53,5	29,5	72,0	145,4	187,4	200,0

Used deep well drilling "SOLO"



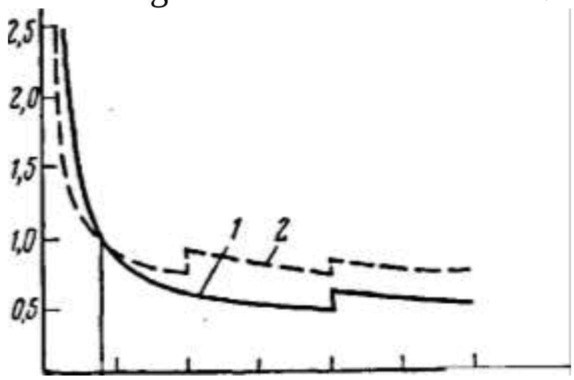
■ Wells drilled in total ▫ including SOLO
Fig. 1.5. Analysis of the efficiency of using drilling equipment at the Kirovsky mine

Analysis of figures (1.1-1.5) shows the trend of replacing pneumatic drill heads with hydraulic drill heads. This is justified only for driving large section workings and when performing mining operations in the case of large section development workings (> 25m). However, as indicated, for example, [21], for portable and telescopic rock drills, the preference for pneumatic types of drill heads remains. In addition, the cost of drilling with pneumatic drill heads in some cases can be lower than hydraulic drill heads, which is due to the high cost of the latter and the insignificant difference in shift performance, as well as the low wages of drillers [62, 95]. The above confirms the relevance and expediency of improving G1BG.

1.2. Directions for perforator improvement

When drilling holes in mines equipped with a pneumatic network, the transition to hydraulic machines is all the more problematic, since the cost of drilling does not include the capital costs of constructing a pneumatic network.

In fig. 1.6, it is shown that there is an area in which the use of pneumatic machines is more cost-effective than hydraulic ones [95]. This is explained by the fact that the cost of a hydraulic machine is 1.5 times higher than that of a pneumatic one, although the hydraulic machine has a higher productivity. With a small production volume, this advantage does not manifest itself.



0,5 1 1,5 2 2,5 3 mln.t/years,

Fig. 1.6. Dependence of the cost of drilling 1 m of a well on a given annual volume of drilling with hydraulic (1) or pneumatic (2) equipment

As new pneumatic drilling technology develops and its productivity increases, the economic performance of pneumatic machines will improve, and the transition to hydraulic IITKU in each case will require careful justification.

The practice of using the first hydraulic drilling rigs has shown that their efficiency increases sharply with the accumulation of experience in their operation. The drilling speed increases as the parameters of the drilling mode become more precise. The number of breakdowns is reduced, which ultimately allows one operator to service a two-three-unit machine.

The economic efficiency of the use of hydraulic SHBU in comparison with pneumatic in domestic practice is considered in [95]. In this work, it is shown that hydraulic MAS are more efficient compared to pneumatic, subject to a high utilization rate of equipment over time.

1.2.1. Possible upgrades of PP63V rock drills

Possible changes in the design of the perforator from the Pnevmatika plant PP63V, PT45. The advantages and disadvantages of the options are presented in Table 1.8.

It is advisable to analyze this table, taking into account the minimum changes in the existing design of the perforator, which will allow manufacturers to switch to the development of new perforators with minimal costs. Since the creation of a new design of the percussion system requires expensive and time-consuming debugging tests.

Modernization options according to pp. 1,3-6 (see Table 1.8) require the development of a completely new design of the rock drill, since the modernization concerns the body and other main components.

Modernization options item 2 (see Table 1.8) can be effectively used on strong homogeneous rocks.

Table 1.8-Possible changes in the design of the perforator plant "Pnevmatika" PP63V

№	Name of changes	Dignity	disadvantages
1	Increase in piston diameter	Increase of the force acting on the piston and the speed of drilling	Requires development of a new rock drill, increased kickback and vibration of the rock drill
2	Increasing the piston stroke	Increased impact energy	Modified perforator barrel design, increased recoil and vibration
3	Reduced valve response time (reduced valve travel)	Increased impact frequency, increased drilling speed	Manufacturing of a new valve box, reaming of new holes in the rock drill body, increased vibration, noise and air consumption

Modernization options point 7 (Table 1.8) does not require significant modernization of the perforator and can be carried out by the repair service, and what is very important can be effectively used on rocks developed under conditions, for example, at JSC "Apatit".

A double impact on a two-phase rock, including hard and soft components (apatite and hard rock), can increase the impact efficiency in the presence of a low-mass striker [7]. Taking into account the important advantages of the modernization option, point 7 (Table 1.8), modernization according to this option is of greatest interest.

1.2.2. Development of new domestic designs of drill heads

As indicated in [97], the introduction of the second stage of promising GOSTs for underground drilling rigs and drilling rigs poses a serious task for domestic machine-building enterprises to increase the productivity of equipment. The solution to this problem largely depends on the results of work on the creation of new, more powerful pneumatic drill heads.

Currently, foreign firms have the opportunity to offer customers, depending on their requirements, several dozen different models of pneumatic drill heads. Their parameters vary within wide limits: cylinder diameter - from 89 to 162 mm, piston stroke - from 34 to 92 mm, impact frequency - from 27 to 56.7 s. " "(Finland) and" Joy "(USA) use a valveless air distribution scheme, Atlas Copco (Sweden) equips the vast majority of its drill heads with valves for this purpose, Gardner Denver and Ingersoll Rand (USA) use valves for this purpose. equally both air distribution schemes.

The overwhelming majority of foreign drill heads have rotation of the drill rod independent of the hammer; only Atlas Copco and Gardner Denver use a helicoidal rod in some models, which provides rotation depending on the piston stroke.

Foreign models of drill heads are designed for a compressed air pressure of 0.56 - 0.7 MPa at its flow rate, depending on the parameters of the drill head, from 7.1 to 29.7 m3 / min.

In company catalogs and brochures, as a rule, the values of the impact energy are not published, but according to the scattered information available, it fluctuates for various types of pneumatic drill heads from 100-I 10 to 250-5-260 J, while the impact power varies from 4 to 5 up to 10 and 1 kW.

These drill heads also differ significantly in their weight - from 65 to 262 kg.

Domestic mechanical engineering cannot provide our mining enterprises with such a wide selection of models of pneumatic drill heads [98]. Currently produced drilling machines PK-60, BGA-1M, PK-75 and 532.07 have impact energy from 85-90 to 150-170 J with impact power from 3.68 to 6.0 kW. This is one of the significant constraining factors in the creation of underground drilling equipment, corresponding in its technical level to the best foreign counterparts.

In order to solve this problem, the Gipronickel Institute [97, 98] developed a type of pneumatic drill heads, in accordance with the requirements of which prototypes of GBP2, GBPZ (VNIPIrudmash Institute) and M4 (Starooskolsk Mechanical Plant) were created. The tests made it possible to determine that the newly created pneumatic drill heads GBGT2, GBPZ and M4 surpass similar domestic and foreign models in terms of their main indicators.

In Gipronikel, a type of hydraulic drill heads has been developed, the implementation of which has contributed to a qualitative change in the direction of work in this area [97, 98]. Developed and manufactured prototypes of hydraulic drill heads GBG-120-300; GBG-230-300;

GBG-300-500 (SKV SGO), as well as GBG6, GBG10 and GBG16 (VNIPIrudmash). For an objective assessment of operational and technical indicators, research tests of the named samples were carried out at the Gipronickel Institute test site.

The main results of field tests of hydraulic drill heads are given in table. 1.9.

Table 1.9-Technical characteristics of hydraulic drill heads

Parameters	Standard sizes							
	ГБГ 6	ГБГ 10	ГБГ 16	ГБГ-120-300	ГБГ-230-300	ГБГ-300-500	лпт 120.01	ГВКС-125
Impact power, kW	6,3	10,5-11,2	16,0	П,4	13,8	17,8	there is no data	14,6
Impact energy, J	128	145-217	227	146	244	270	there is no data	250
Impact frequency, s'1	49,2	72,6-51,7	70,4	78,3	56,7	66,0	55,8	58,4
Pressure in the pressure line of the striker, MPa	19,0	20,0	23,5	17,0	17,0	16,5	18,0	20,0
Liquid consumption with a striker, dm3 / min	65,0	75,7+97,0	103,3	90,0	98,6	158	80,0	70,0
Rotation frequency, s'1	5,0	4,8	4,2	4,0	3,7	2,8+3,4	4,0	5,2
Torque, N m	160	235	300	300	300	500	there is no data	310
Pressure in the pressure head line of the rotator, MPa	12,3	13,2	17,5	10,0	14,0	13,5	9,0	7,0
Rotator fluid flow rate, dm3 / min	34	48	56	79	49	80+96	42	62
Weight, kg	63,5	120	145	145	145	145	there is no data	125

Comparison of the test results of various drill heads shows that models with relatively similar parameters of percussion units differ significantly in the achieved drilling speed [98]. First of all, this can be explained by the design features of the heads that determine the efficiency of rock destruction (impact speed, ratio of energy and impact frequency, number of impacts per revolution, etc.). The validity of this conclusion is confirmed by the calculations of the specific energy consumption for all the models considered based on the test results. It has been established that the highest value of this indicator (0.47-I), 37 kWh / m) is in the GBG-120-130 and GBG-230-300 heads, which in their energy parameters are superior to the GBG10 drill head, but are significantly inferior to it. by drilling speed.

Of particular interest is the comparison of drilling performance in a test area with pneumatic and hydraulic heads, which are similar in impact power. When working at nominal modes, the drilling speed with hydraulic heads is 1.5-I, 65 times higher than that of pneumatic ones, and the specific energy consumption is 3.3-5-4 times lower (as already noted, in real conditions, ensure the nominal mode the operation of pneumatic drill heads is very difficult, often impossible). In addition, hydraulic heads have a slightly lower weight than pneumatic ones.

At the same time, during field tests of hydraulic drill heads designed for drilling boreholes, it was found that their design requires improvement in order to eliminate the identified shortcomings. In particular, during the operation of the GBG6 head in all modes, increased pulsation was observed in the sleeves of the drain line, caused by the absence of a battery in this line; at the GBG10 head, there were cases of jamming of the striker's striker, one of the alleged reasons for which could be considered an unsuccessfully chosen design of sealing cuffs; at the GBG16 head, the design of the spool of the striker needs to be improved. After the necessary development work and industrial tests, these drill heads, which showed the best results in comparison with other models, can be recommended for serial production.

The GBG-300-500 drill head with the same drill bit diameter and well depth showed 1.4-I, 6 times more productivity than pneumatic GBPZ and M4 [97, 98]. At the same time, as well as for borehole drill heads, a significant (3.0-5-3.2 times) decrease in specific energy consumption was observed. Comparison of the operational and technical indicators of various types of drill heads obtained under the conditions of the test site confirmed the significant advantage of hydraulic heads compared to pneumatic ones in terms of the technical drilling speed (1.5-4-1.65 times) and specific energy consumption (3.3- M, 0 times).

Heavy-duty hydraulic and pneumatic heads can only be used in conjunction with manipulators and drilling rigs. Therefore, their use in auxiliary operations as portable drilling devices is impossible, which confirms the need to develop new designs for portable rock drills as well.

1.2. Ways to improve drilling rigs

A further increase in labor productivity while drilling blast holes, as well as in exploratory drilling [25, 32], should occur on the basis of such developments that will not only increase the ROP, but also simultaneously improve the use of working time. This is due to the fact that an increase in mechanical speed within certain limits leads to a decrease in the growth of labor productivity, since at the same time the proportion of auxiliary operations increases. In this regard, the intensity of growth in labor productivity gradually decreases with an increase in mechanical speed.

The development of new types of rock cutting tools is associated in the future with new principles of destruction of rocks [25]. However, the analysis carried out by SKB VPO "Soyuzgeotekhnika" shows that new methods of destruction of rocks in the near future cannot be used effectively enough (Table 1.10).

In most cases, their use makes it difficult to ensure high quality sampling of rocks due to changes in their properties, and, in addition, all these methods are generally suitable for the destruction of only some types of rocks.

Table 1.10-Mechanical speeds of the latest types of drilling

Drilling type	**Breaking method**	**Mechanical speed,m / h**
Electro-hydraulic, explosive, erosional, ball-jet, hydro-pulse ultrasonic	Mechanical	1,0-86,0
Thermodynamic, induction, high-frequency, electric arc	Thermal	1,5-34,0
Thermoelectric, nuclear	Melting	0,6-1,7
Electron beam, laser, plasma	Thermal, melting	0,1-7,0

The main direction in the development of exploration drilling technology should be carried out through the intensification of all components of operations. The productivity, for example, of high-speed diamond drilling can reach 20CH-2500 m / st.-month, and hydropercussion-diamond drilling in hard rocks - 1 000 m / st.-month. However, as calculations show, a two-threefold increase in the ROP makes it possible to increase the productivity of the rig per month by only 30-40%. The most promising can be considered such new drilling methods that reduce the time for all operations of the production process (deepening, transportation of core to the surface, round-trip operations and assembly and dismantling works). These requirements are met by the diamond method of drilling with hydrotransport of core (cuttings) and drilling with the use of shells with removable core receivers - SSK and KSSK.

Consequently, for the next period of time, the existing methods of mechanical destruction of rocks will prevail in exploration drilling. The same can be said for drilling blast holes (Table 1.11). Development of ore deposits in open pits is associated with a large volume of drilling and blasting operations, in which the most laborious operation is drilling wells. Drilling can be carried out by drilling rigs of various types of domestic and foreign production, therefore, the issue of choosing the most effective type of rig for a particular mining enterprise and increasing its productivity is urgent.

Table 1.11-Conditions for the application of methods of mechanical destruction of rocks in exploration drilling

Drilling method	Mining and geological conditions		Mechanical speed, m / h	Drilling interval without lifting the drill string, m
	Well depth, m	Rock category by drillability		
Diamond drilling				
With hydrotransport of the core	100-800	И-1У	15-25	400-800
		У-УП	4-6	200-300
With removable core barrel	100-2000	У1-УИ	3,5-6	80-200
			3-4	30-40
ith removable core barrel and interchangeable rock cutting tool	100-2000	У1-УИ	4-7	Corresponds to the depth of the well
		УШ-Х	3,5-4,5	
High-speed diamond	100-500	УШ-Х	9,0-15,0	4-6
		х-хи	6-7	3-4
Rotary percussion drilling				
Water hammer machines	500-1000	У-Х	4-5	4-9				
Coreless drilling				
Roller bits	100-1500	Н-У	60-80	100-150
		У1-У11	3-6	40-60
		УШ-1Х	2,5-3,5	20-30
		Х-Х1	2,0-2,5	10-12

Roller-cone drilling rigs (SBSH) are widely used for open pit mining and in underground conditions. The principle of roller cone drilling is as follows: from the drill through the drill string to the roller cone bit, the torque and the required axial force are transmitted [20, 46, 76]. When rotating, the cutters, which sit freely on the axes of the chisel pins, roll along the bottom, while the bits penetrate into the rock and destroy it. Removal of destruction products from the bottom of the well is carried out with compressed air or water supplied to the bottom through the drill string. Known for high efficiency of drilling when striking a combined, having a leading edge roller cone bits. In this case, the average drilling speed is approximately doubled [96]. However, combined bits have a complex structure, are expensive, and require a complicated manufacturing technology. The use of standard DTH hammers in a set with serial cutters has a number of disadvantages: the durability of the bit decreases (due to a decrease in the service life of the bearings in the legs), the vibration of the drill string increases.

Comparative analysis of designs and technical and economic parameters of known types of drilling rigs shows that the modernization of the SBSH-250MN machine should go, among other things, along the path of improving the vibration modes of the machine [38, 45, 67]. The use of types of drilling rigs that are rational for the given conditions and rational modes of drilling make it possible to increase the productivity of the drilling process and improve the working conditions of drillers, which increases the efficiency of its use.

Known studies of vibration modes of operation of drilling rigs SBSh, on the theoretical substantiation of the effectiveness of the use of tools to increase the drilling speed and durability of roller cone bits and rods and damping devices [16,37].

A number of works are devoted to the calculation of the longitudinal vibrations of the drilling string: Kutuzova B.N. [57], Kantovich L.I., Dmitrieva V.N. [45], Zagrivniy E.A. [37, 38] and others. A feature of these works is the use of the drill rod model as a rigid rod. However, for a drill string of sufficient length (about 12h-16m), this approach requires justification. Drilling rod, in some cases, should be considered as a rod with a distributed mass. To reduce the vibration of the SBSh train, various technical means have been developed, in particular in [38], it was proposed to install a pneumohydraulic shock absorber between the rotator and the rod.

To intensify the drilling process of the SBSH-250 rig, it is possible to use a down-the-hole hammer, when a power pulse is additionally applied to a rotating roller cone bit under axial load. However, the use of standard DTH hammers can lead to rapid cone failure as a result of additional shock loading. In order to protect the cutter from the harmful effects of shock loading, the DTH hammer needs to be modernized, for example, using the ideas embodied in the new drilling method [72].

It is planned to modify and create new rotary cutter drilling rigs for opencast mining in the following main areas [105]: control of wells and operating modes; driver comfort; diagnostics (diagnostic devices); damper system.

1.5. Analysis of methods for selecting optimal parameters and operating modes for drilling equipment

1.5.1. Determining the performance of drilling machines

It is possible to determine the reasonable performance of drilling machines, both during their creation and operation. Analysis of the factors that determine the net drilling speed and the time spent on performing auxiliary operations allows you to choose a rational type of machine for specific mining and geological conditions, to determine the effective drilling mode [42, 61, 62].

There are two methods for determining productivity (drilling speed) [49]. The first method is based on the statistical processing of a large number of reliable time observations of the operation of the machine. The standardizer indicates the net drilling speed (bit feed rate to the bottom hole), depending on the hardness of the drilled rocks and the average value of the machine's operating performance. Currently, there are approved drilling machine performance standards for all major mining industries.

The advantage of this method is that it simply and accurately allows you to set the average performance of a large group of machines of the same type. The disadvantage is low accuracy and lack of consideration of the manufacturing quality of the drill head and operating conditions (changes in air pressure, engine power, etc.).

The second method is the calculation of a technically justified performance, taking into account the characteristics of a particular machine. At the same time, there are three types of productivity of drilling machines: theoretical, technical, operational.

For rock drills, machine tools with downhole (for example, BP-100 type) and remote pneumatic hammers (for example, SBU-70 type), rotary drilling machines (UBSh type), the drilling speed [9, 33, 41, 87, 107]:

$$\mathbf{V_т = \frac{2hn}{1000}, м/мин} \qquad (1.1)$$

where h- is the depth of penetration of the bit per blow (in combination with the static feed force for rotary percussion drilling machines), mm;

n-is the number of revolutions of the bit per minute, rpm. In one revolution of the bit, the bottom of the well is cleaved to a depth of 2-k.

The rate of drilling of machines of percussion, percussion-rotary in rotary-percussion action depends on the combination of the following main factors: rock hardness, characterized by the hardness coefficient according to the Protodyakonov scale, or the temporary compressive strength, or the hardness category according to drillability; impact forces or impact energy A and feed force (pressing the bit to the bottom) Pp; borehole diameter c1; type of crown; the angle of rotation of the crown (bit) for one blow a; the rate of removal of drill fines from wells.

ROP for machines of this type is determined experimentally or by empirical formulas. For rotary percussion drilling machines for boreholes and small-diameter blast holes with a drilling depth of 3-4 m, the drilling speed is recommended to be determined by the formula [9, 49]:

$$\mathbf{V_T = \frac{C0K1v\acute{\lambda}(Fp+Fy)^n}{\sigma(Sn+\Delta St)}, m/min} \qquad (1.2)$$

where C_0- is a coefficient characterizing the resistance of the rock to indentation with an increase in the penetration depth, mm / rev;

K_1- number of crown blades; V is the rotation speed of the crown, rpm;

L - coefficient taking into account the degree of cleaning the bottom of the drill fines;

ʎ - resistance of the rock to indentation, N / mm;

Fp- is the strength of a single blow, N; Bn is the initial contact area of the sharp crown with the rock, mm;

ΔSt-increment of the blunt area of the blades bits during drilling;

m - exponent, depends on the properties of rocks, m = 0.67 -> 0.77 at t = 8-r20.

L.I. Baron and N.S. Rodionov is recommended to determine the mechanical speed of drilling holes with perforators according to the energy formula [49]:

$$\mathbf{Vt= k\frac{An}{Dk},} \qquad \textbf{(1.3)}$$

where A- is the impact energy of the perforator;

n_p- is the number of perforator piston blows per minute;

D_k- crown diameter, mm;

V_m - is an index of crushing characterizing the resistance of rocks to dynamic fracture by the method of crushing, K is an empirical coefficient, selected depending on the properties of rocks.

Operational productivity is the maximum possible productivity of the machine, taking into account the inevitable downtime associated with drilling technology alone. Downhole (at the site) machine downtime is determined by the organization of work. In general terms, the operational performance of a drilling machine is expressed by the formula:

$$L_g = \frac{T - t_{пз}}{\frac{1}{K_{\omega}V_1 z} + A_в}, \text{ м/смена,} \qquad (1.4)$$

where T-is the duration of the shift, min;

t_{pz} - time spent on preparatory and final operations at the beginning and end of the shift;

K_{od} - coefficient of simultaneity; with two drill heads on the rig Code = 0.7; b is the number of simultaneously drilled holes (manipulators,drill heads) by one machine;

A_v- the time spent on performing auxiliary operations during drilling, referred to the meter of the drilled well, this includes the time spent on rearranging and fixing the drilling rig (drilling rig) for drilling a new well C, time and on the extension of rods when drilling wells with a depth of b; time to replace bits and ', time to pull the rods out of the well after drilling it.

1.5.2. Analysis of methods for calculating the percussion system of drilling machines

In the above formulas, not all factors are taken into account (there is no possibility of taking into account additional effects on the piston and changes in the type of action: with variable force, impulse, etc.), therefore, many authors pay attention to the method of determining the efficiency of the transmission of shock while drilling.

The work of impact of a perforator and other machines of impact and impact-rotational action turns into useful work of destruction due to the transfer of energy by impact, stored by the hammer piston, to the executive body (drill, bit, etc.). The greater part of the piston energy is transferred to the executive body, the higher the impact efficiency, the greater the performance of the hammer, and the more efficient drilling. Therefore, it is necessary to know the factors that determine the relationship between the energy supplied by the piston and received by the actuator.

er

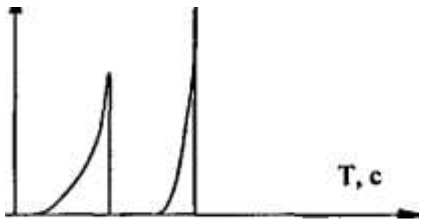


Fig. 1.9. Optimal shock impulse shapes recommended by K. I. Ivanov

However, according to Vasiliev [21], PBG are unlikely to be replaced by GBG for auxiliary work and as telescopic perforators. At the same time, many modern works indicate serious R&D and R&D associated with the improvement (modernization) of known or creation of new PBG designs [4].

In the works of Pavlov A.C., Ushakov JI.C. and Lazutkina A.G. [4] examines the studies of hydraulic percussion machines, 'including the "prolonged shock pulse", and indicates the need for a serious theoretical substantiation of the effects obtained during the transfer of kinetic energy in the system "firing pin - intermediate links - working tool". Mathematical models and algorithms for calculating hydraulic hammers are considered in detail in the works of L.S.Ushakov, V.A.Kravchenko. [5], however, in these works, the so-called instantaneous impulse is considered and it is mainly about single shocks of high power.

New efficient machines, both pneumatic and hydraulic, are considered in [27], unfortunately, they do not present the results of their work in industrial conditions and design features.

In the works of S.V. Belokobylsky. [14] considers the original theory of shock-self-oscillating motion of a rock-cutting tool (roller cutter); unfortunately, the specific parameters of the impact device cannot be approximated by the calculated data on this theory.

1.5.3. Methods for determining the efficiency of transmission of impact

Classical mechanics considers that upon impact, the acting forces are applied to the center of inertia of the colliding bodies. In the presence of stress waves (hence elastic deformations), different points are loaded in different ways and move at albeit very small, but different distances [9].

Let us consider in more detail, according to [4], the theory of impact in the formulation of "classical mechanics" and "wave theory of Saint-Venant". When accepting the postulate that the momentum of the system consisting of the piston of the striker and the drill remains unchanged, i.e. = m, u, + m2u2, the ratio of the relative speed of the system (drill-piston) after impact to its relative speed before impact is

When, for example, rods collide, the experimental values and those calculated using the above formulas are different. The exception is some special cases, for example, equal or close to each other masses. When the collision of rods of different masses occurs (the mass ratio is 2-5-5 or more), or when the transmission of impact occurs with a large difference in the lengths of the rods, these practices differ from those calculated according to the formulas given (especially under the second condition).

Classic mechanics do not take into account the impact time. The wave theory of Saint-Venant assumes that the impact time is equal to the travel time of the wave in both directions along the shorter rod:

Practice shows that these provisions are also valid only for a particular case - provided that the length of the colliding rods is much greater than their transverse dimensions. Moreover, what is especially important, the ends of the elements of the system, which are in contact upon impact, are considered absolutely flat.

The classical theories are based on the idealization of certain conditions of impact. Absolute hardness in the transfer of energy by impact presupposes the propagation of any stress with an infinite speed classical mechanics of a rigid body (stereomechanics). The condition of absolutely flat ends of the rods means simultaneous contact over the entire end surface - wave theory. In this theory (Saint-Venant) it is indisputable that a real body has elastic properties, and is not absolutely rigid. Consequently, any stress (force action) propagates with a finite speed determined by these elastic properties, which is equal to the speed of sound propagation in the medium under consideration. In the theory of steroomechanics, it is indisputable that the same impulse £ -Pt is applied to the colliding bodies (P is the collision force, and t is the time of its action), respectively, it is true that the change in the momentum is expressed by the dependences mV = Pt and P = mj (j - acceleration of the body), because they are obtained from Newton's second law.

In the drilling laboratory of the I.M. A.A. Skochinsky developed a method for determining the efficiency of transmission of impact, based on both classical theories. The main provisions of this method are that a certain critical mass (m_{kp})

is considered - this is the part of the mass of the bar (m_2) that takes part in the impact and is determined on the basis of the wave theory. This mass can change with the same striker due to a change in the elasticity of the rod end with a mass m and an increase in this connection t_{yd} (the length of the "disturbed" part of the rod Λ = a*t). Therefore, a part of the rod with mass m_2 (the length of which is equal to the difference "L=Λ," remains unperturbed upon impact), which means that it can be neglected and it can be assumed that the impact occurred between the impactor of mass mi and mass m_{kp}. In the most general form, for the collision of bodies of irregular shape (at $\mathcal{E} = 1$):

$$\eta_{пу} = 4\frac{m_1 m_{kp}}{(m_1 + m_{kp})^2}$$

When three bodies collide, the energy transferred to the third element of the system:

$$\eta_{ПУобщ} = \eta_{пу}^2,\ \text{если } m_1 = m_3$$

$$\eta_{ПУобщ} = \frac{4m_1 m_{kp}}{(m_1 + m_{kp})^2} = \frac{4m_{kp} m_3}{(m_{kp} + m_3)^2}\quad \text{если}\quad m_1 \neq m_3$$

Considering m_{kp} free mass, impact of rods c by the masses $m_2$and m_3 can be essentially thought of as a collision between m_{kp} and m_3.

The following results were obtained experimentally [9].

1. When the striker m_1 collides with rods of the same diameter, but different lengths – from $\ell_2 \approx \ell_1$ before $\ell \approx 33\ell$ obtained that afterℓ_2>2,9ℓ_1, rod rebound m_1 remains constant. Hence, m_{kp} for the rods under consideration is 2,9 m_1 (according to Saint-Venant m_{kp} =2m_1)

2. With constant mass m_2 =33m_1 and the change in the configuration of the end face of the striker mi, depending on its curvature, the value m_{kp} practically reached a sixfold value at a conical end with a radius of curvature of 1/2 of the radius of the rod.

However, this calculation method does not take into account the occurrence of permanent deformations. In addition, at large radii of curvature of the rod mi, the t_{yd}, and hence m_{kp}, which is difficult to determine in practice. For calculating the parameters of the percussion system when using short rods (drilling of auxiliary holes is common and important), these methods are not entirely acceptable.

A decrease in the drilling speed with an increase in the depth of the well is explained not only by the low impact efficiency, but also by other reasons: insufficient torque, bluntness of the bit, deterioration in the efficiency of removing drill bits, decrease in air (liquid) pressure supplied to the hammer, etc.

Evaluation of the efficiency of percussion devices using the methods of the classical theory of impact was made in [59]. In this work, the transmission coefficient of impulse devices with one moving mass is estimated by the ratio of the velocities of the striker U and the working tool V:

Highest efficiency value ($\eta_{уд}$) impact of the tool on the striker is 0.84 at a=1. However, the real mass ratio usually differs from the idealized one, the mass of the striker is 3/5 times less than the mass of the tool, therefore the efficiency of the installation is approximately

0.46 /0.53. If an intermediate mass between the working tool and the striker is introduced into the percussion device, then at a certain mass ratio it is possible not only to maintain the energy transfer coefficient, but also to reduce the recoil of the mechanism upon impact. When calculating this statement, the same conditions were met as with one moving mass. Graphs of changes in the coefficient of energy transfer from the working tool to the striker are shown in Fig. 1.10. Different curves correspond to different ratios of intermediate mass to impactor mass $P = m_{зк}/m_{нв}$.

The mass ratio at which the efficiency of the installation is equal to the efficiency in the first variant (without intermediate mass) corresponds to m_2:m_{pr}: m_1=1:3:5, however, in this case, the energy output to the body of the striker will be no more than 5-10 % [9].

As can be seen from the above materials [9], in calculating the impact efficiency, an important role is played by the coefficient of recovery upon impact (k;Ɛ); in other theoretical works [7] this parameter is designated R. Pull up R.Yu. [7] in the method for determining the main parameters of the hydraulic hammer also takes into account the velocity recovery factor, denoting it K_1 (calling it the "velocity reflection coefficient"), and recommends taking it in the range of 0.1-0.7), Emphasizing that the rebound of the piston has a positive effect on the efficiency of the hydraulic hammer, as it increases the frequency of the impact (through an increase in the response speed of the hydraulic control devices).

In these works, S.A. Lyaptsev [9] and others considered a single impact and did not consider options for other ratios of the masses of the shock system, including no data on the use of an intermediate striker of low mass.

1.6. Statement of the research problem

On the basis of the above analysis of methodological approaches to calculating the parameters of percussion systems, and known designs of drilling tools, the goal, the idea of work and the main tasks of research can be formulated, which are as follows.

The purpose of the work is the development of modernized designs of pneumatic perforators and downhole pneumatic hammers with the optimization of their main parameters according to the developed mechanical and mathematical models to increase the drilling speed and durability of the drilling tool.

Idea of work: modernization of the design schemes of rock drills and submersible pneumatic hammers, taking into account the increase in the efficiency of impact transmission with the transition to a quasi-plastic blow based on the bounce of a smaller part separated striker and obtaining a rational form of shock impulse, which allows for effective destruction of the rock.

The main tasks of research:

1. Analysis of existing and prospective methods and technical means of conducting drilling operations in the conditions of JSC "Apatite".

2. Development of mechanical and mathematical models for describing processes in percussion systems of drilling machines.

3. Development of a methodology for calculating the parameters of the elements of the "piston-striker-rod" shock systems to achieve an increase in the impact efficiency.

4. Substantiation of the layout diagrams of the modernized rock drills and DTH hammers, their designs and areas of application.

5. Analysis and experimental research at the stands and in the mine conditions of the main parameters of the structures of the modernized rock drills and submersible hammers for drilling rigs.

6. Development of designs of modernized rock drills and downhole hammers for drilling rigs and determination of their rational parameters using algorithms that take into account the dynamic processes of modernized rock drills and hammers.

CHAPTER 2. THEORETICAL RESEARCH ON JUSTIFICATION OF THE PARAMETERS OF NEW DRILLING MEANS

In accordance with the previously set goal, the tasks of theoretical research can be formulated. They cover solutions to the problems of the interaction of the striker with the rod, taking into account the wave processes of compression-expansion in its elements occurring in the shock system, the efficiency during impact, and the shape of the shock pulse. At the same time, the main task is still considered to be the need for a rational selection of the parameters of the percussion system and the drill head itself.

As indicated in paragraph 1.5., It is advisable (according to Kolomiytsov MD [9]) to consider the impact, both from the point of view of the classical theory of impact, and according to the wave theory, the results obtained for the two considered approaches must be compared and analyzed. To do this, this section solves the following tasks:

1. Acceptance of assumptions and formulation questions for the correct determination of the efficiency at impact.
2. Solution of the problem of determining the region of existence of a quasi-plastic impact under the condition that the rod is considered as an absolutely rigid or as an elastic body.
3. Solving the problem in a parametric form to substantiate the bounce process in the shock system.
4. Comparative analysis of the range of applicability of the stereomechanical and wave theories when considering shock processes.
5. Solving the problem in a parametric form for obtaining shock impulses of various shapes in the presence of a spring-loaded striker.

2.1. Background of creation of new drilling tools

The theoretical substantiation of possible directions for improving the percussion system is based on the results of studies of the operation of portable perforators with an improved percussion system.

It was experimentally found that in some cases the drilling speed increases (up to 50%) if an additional body of small mass is installed in the gap between the rod and the striker - the striker. It is this kind of modernization with minimal design changes that makes sense for portable and telescopic rock drills. Initially, two hypotheses were accepted to describe the process of drilling with a double hammer rock drill.

Hypothesis 1. The destruction of a mountain range is a complex physical process. As shown in Figure 2.1, when a single blow is applied to the rock, a "glancing" blow is possible (bit position A: the blade will jump in the direction of apatite, as a softer rock), as a result of which little energy is transferred to the rock, which is characterized by low efficiency.

Double impact is used to reduce the possibility of getting a "sliding" or "side" impact, due to the striker applying a preliminary "cut" or notch. To do this, we will use the momentum formula taking into account the coefficient of impact transfer from the crown to the rock (Fig. 2.1, a).

$$\mathbf{K_{кр} * P_1 * t_1 = P_2 * t_2,} \qquad \textit{(2.1)}$$

where: $K_{кр}$ - bit-to-rock transfer coefficient;

P_1 - force with which the crown acts on the rock, H;

t_1 - the duration of this exposure, c;

P_2 - the force that is transmitted from the crown to the rock, H;

t_2 — the duration of the transfer of force from the crown to the rock,

The coefficient of transmission of impact energy from the bit to the rock can be set, in the range from 0.4 to 0.7 [77].

$$\mathbf{P_2 = \sigma_{czh} * S,} \qquad \textit{(2.2)}$$

where: σ_{czh} - contact strength of rocks, MPa;

S - area, m^2

Using the properties of an equilateral triangle, the relationship between the area and the height of the cut can be set (Fig. 2.1, a):

$$\mathbf{h = \sqrt{s * 0,7}} \qquad \textit{(2.3)}$$

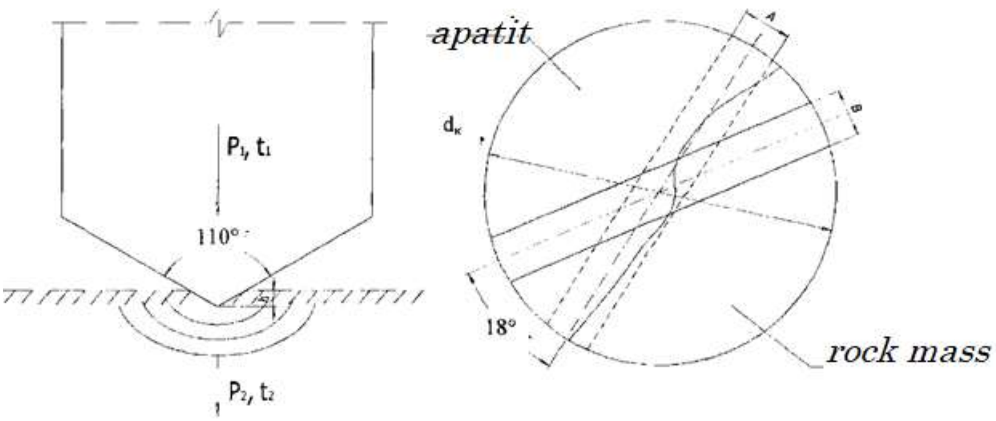


Fig. 2.1 Scheme of interaction of a crown with a rock face: a) design scheme; b) scheme of traces of destruction

where h - is the depth of immersion of the crown in one blow, m.

Hypothesis 2. In the process of rapprochement between the striker and the barbell, the onset of bounce of the striker located between them is very likely. In other words, a series of repeated collisions of the striker against the approaching surfaces of the ends of the rod and striker occurs. As a result, all three bodies "stick together" in a finite time. The result of the movement of the striker is as if the impact were purely plastic. The validity of this statement was also confirmed quantitatively. Thus, one can

to make impact interaction quasi-plastic and, thus, increase the efficiency of drilling.

2.2. Impact of the pneumatic impact on the absolutely rigid bar "dribbon - quasiplastic impact"

After the collision along the length of the rod, the longitudinal elastic wave with speed

$a = \sqrt{\frac{E}{P}}$, where *E* — Young's modulus, *p* – volumetric density [7, 8, 9, 11, 22, 66, 67 e t.c]. Consequently, the total propagation time of this wave is $T_{впл} = 1_{шт}\sqrt{\frac{P}{E}}$,, where $1_{шт}$ — rod length.

It is known that if this time is significantly shorter than the impact time Tud, then the impact interaction between the rod and the striker can be described by the theory of stereomechanical impact of absolutely rigid bodies [66, 67]. According to this theory, with such a collision, the law of conservation of the total momentum is fulfilled. Assuming that the bar is motionless before hitting, we can write

$$m_1V_1^* + m_2V_2^* = m_2V, \qquad (2.4)$$

Here m_1 and m_2 — weight of the rod together with the crown and striker,

V — pre-impact speed of the striker,

V_1 и V_2 - post-impact values of the rod and striker speeds. According to the recommendations of vibration theory [11] weight of the bar (m_1) should be taken equal to one third of its length ($m_1 = m_{шт}/3$). Relation (2.4) should be supplemented with the well-known equation for recovering the relative velocity of the striker

$$V_2^* - V_1^* = -RV \qquad (2.5)$$

where R - coefficient of recovery, depending on the material and shape of the impacted bodies. According to [56] upon collision of steel bodies R = 5/9.

Solving a system of two linear equations with two unknowns, we arrive at the following expressions for the post-shock velocities:

$$V_1^* = \frac{m2(1+R)V}{m1+m2}$$

$$V_2^* = \frac{(m2 - m1R)V}{m1+m2} \qquad (2.6)$$

In case of absolutely elastic collision, the general energy ratio will have the form:

$$\frac{m_2V^2}{2} = \frac{m_1(V_1)^2}{2} + \frac{m_2(V_2)^2}{2} + \Delta A \qquad (2.7)$$

On the left side of this equality is the initial kinetic energy of the striker. The first and second terms on the right characterize the post-impact energies of the rod and striker. As for the last term, it determines the energy losses upon impact on plastic deformations, destruction of colliding bodies in the contact zone, and others. Energy losses are determined by the formula:

$$\Delta A = \frac{1-R^2}{2} - \frac{m_1 - m_2}{m_1 + m_2} V^2 \quad \textbf{(2.8)}$$

The subsequent destruction of the rock is carried out due to the presence of the post-impact kinetic energy of the rod. Therefore, the efficiency of the percussion drilling process is determined by the formula.

$$ŋ = \frac{m^1 (V^1)^2 / 2}{m_2 V^2 / 2} \quad \textbf{(2.9)}$$

$$ŋ = \frac{m_1 m_2 \quad (1+R)^2}{(m_1 + m_2)^2} \quad \textbf{(2.10)}$$

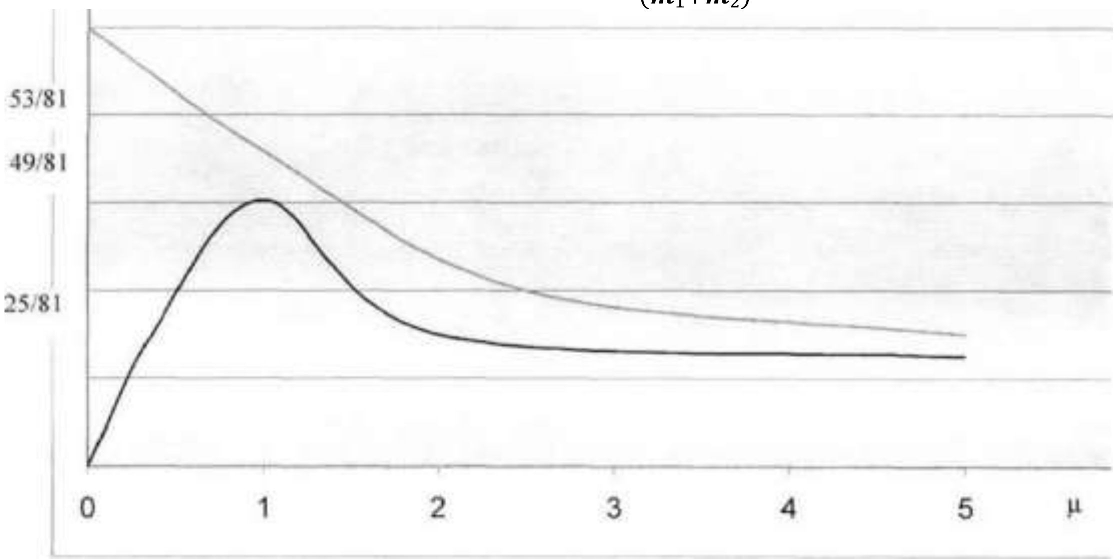


Fig. 2.2. Dependence of the efficiency of shock systems on the parameter ц = m_1,/m_2 for different coefficients of recovery on impact

Note that in [56], the kinetic energy of the striker rebounded after the impact is also added to the useful work. Therefore, overestimated values of the efficiency were obtained there. ŋ *(fig. 2.2),* which was determined by the formula.

$$ŋ^i = \frac{1+R^2}{(m_1 + m_2)^2}$$

Graphical representation of dependency data when R = 5/9 are shown in the same figure 2.2 by solid and dashed lines. The graph of the dependence of the efficiency ŋ on the parameter ц=m_1/m_2 at R= 5/9 shown in Figure 2.2 by the dark line.

The graph shows that the maximum value ŋ = 49/81 is achieved at ц = 1 (m_1 =m_2). Thus, in this case, the mass of the piston and the rod are equal to each other.

So, according to (2.10), the efficiency increases monotonically with increasing R. Formula (2.10), however, turns out to be invalid in the case of an absolutely inelastic collision, when R = 0. Indeed, in this case, the post-impact velocities are equal:

$$\mathbf{V^*=V_1=V_2=(m_2V)/m_1+ m_2} \qquad \textbf{\textit{(2.11)}}$$

This means that after the impact, the rod and the striker "stick together" and their joint post-impact energy works to destroy the rock. Consequently, the efficiency in this case should (in contrast to 2.9) be determined by the formula

$$\eta_0=\frac{(m^1+ m2)(V^+)^2/2}{(m_2V^2)/2} \qquad \textbf{\textit{(2.12)}}$$

Hence, in corollary (8), we have

$$\eta_0 =m_2/(m_1m_2) \qquad \textbf{\textit{(2.13)}}$$

The question arises: when absolutely inelastic (plastic R = 0) collision turns out to be more effective for drilling than collision is not absolutely elastic (0 <R <1). Чтобы ответить на этот вопрос, положим г) $\eta_0 > \eta$ Expanding this inequality with allowance for (2.10) and (2.13), we obtain

$$\mathbf{m_2>m_1(2R +R^2)} \qquad \textbf{\textit{(2.14)}}$$

Hence, it can be seen that an absolutely inelastic collision will be more favorable if the rod mass m is small.

Inequality 2.14 is a sufficient, but not a necessary condition for the greater efficiency of the absolutely inelastic collision of the striker and the rod during drilling. The fact is that after a plastic impact, the drummer and the rod "stick together", that is, they move together. In this case, the hydraulic force $F_{гидр}$=pS by means of a rod it is transferred directly to the face. Therefore, the equation of post-impact braking of the striker and the rod has the form

$$\mathbf{(m_2+m_1)v = F_{гидр\ -N}} \qquad \textbf{\textit{(2.15)}}$$

Here F- is the air (liquid) pressure; N is the total longitudinal force of the rock resistance to destruction;

V-is the drilling speed.

Differential equation (2.15) must be integrated with the initial condition t=0, v=V* according to (2.11).

If the collision is not absolutely elastic, then the hydraulic force, acting on the bounced striker should not be taken into account, and (2.12) will take view

$$\mathbf{m_1,\bullet\ v = -N} \qquad \textbf{\textit{(2.16)}}$$

and the initial conditions are of the form: t=0, V=V* according to (2.6).

2.3. Quasiplastic impact in the interaction process pistons and barbells

Let us assume that the shock interaction between the piston and the rod is not absolutely elastic (R> 0). In this case, the coefficient R is very small, so that inequality (2.14) is satisfied. The initial collision occurs at a certain moment tdr, when the magnitude of the pneumatic (hydraulic) force is positive, that is, it is directed towards the approach of the rod and the piston. In this case, bounce occurs subsequently, which is called quasi-plastic impact [66]. We are talking about a sequence of repeated increasingly frequent collisions of decreasing intensity to zero, which in a finite time ^ ends with the "sticking" of the striker with the barbell (Fig. 2.3).

$$\mathbf{tdr} = \frac{\mathbf{2mRV}}{\mathbf{F(1-R)}} \qquad \mathbf{(2.17)}$$

Here F - the magnitude of the pneumatic (hydraulic) force. In this case, as shown in monograph [6], the final result of the motion will be the same, or almost the same, as if the initial collision were plastic (absolutely inelastic) and therefore there were no repeated collisions at all.

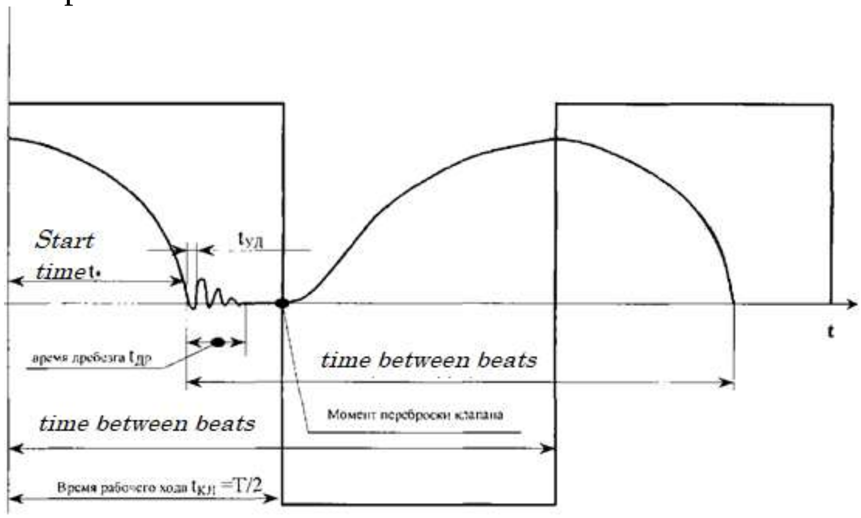


Figure 2.3. The graph characterizing the bounce process (the nature of the change in the effort in barbell in time)

All this, due to (2.14), makes the drilling process just as efficient. A necessary condition for the existence of such a motion is the fulfillment of the inequality

All this, due to (2.14), makes the drilling process just as efficient. A necessary condition for the existence of such a motion is the fulfillment of the inequality

where tk is the closest moment of valve actuation, which coincides with the tk

$$t_k > t_{dp} = \frac{2mRV}{F(1-R)} = \frac{2m_2RV}{F(1-R)} \qquad (2.18)$$

moment of changing the direction of the hydraulic force F. In other words, the moment of end of bouncing must precede the moment of changing the direction of force F. between the piston and the rod is absent.

However, in this case, it is also possible to realize bounce by installing an additional body between the piston and the rod - a striker of small mass. Quasi-plastic impact in a system of three bodies moving rectilinearly was also studied in the monograph [66]. In particular, it was established there that for the implementation of bounce it is necessary to satisfy the inequality.

$$\frac{(\sqrt{R_1}+\sqrt{R_2})^2}{(1+R_1)(1+R_2)} < \frac{m_1 m_2^{\prime}}{(m_1+m_2^{\prime\prime})(m_2^{\prime\prime}+m_2^{\prime})} \qquad (2.19)$$

for generality, it is assumed that the recovery coefficients for the impact of the striker on the rod R_1 and the striker on the piston R_2 are, generally speaking, different. In the special case, when $R_1 = R_2 = R$, instead of (2.19), we can write:

$$\frac{4R}{(1+R)^2} < \frac{m_1(m_2-m_2^{\prime\prime})}{(m_1+m_2^{\prime\prime})m} \text{ или при } \mu=\frac{m_2^{\prime\prime}}{m_2} \text{ и } \nu=\frac{m_2}{m_1} \rightarrow \frac{4R}{(1+R)^2} < \frac{1-\mu}{1+\mu\nu} \qquad (2.20)$$

Figure 2.4 shows a parametric plot built from theoretical data for various v ($v=m_2/m_1$, $m_1=mht/3$, mht[11], m_2 - the total mass of the piston-striker). The bounce area is limited by a curve and two axes, i.e. when a point that meets the specified or selected parameters falls into the area below a certain curve V = const - the bounce process should take place, but at the same time, a smaller part of the striker (striker) should be of a certain mass. The abscissa shows the parameter characterizing the ratio of the mass of the small part and the striker (striker) m_2' to the mass of the whole drummer m_2; $m=m_2/m_2$, $m_2^{ii}+m_2^{i}=m_2$.

Axis ordinates - speed recovery factor (R). Its value characterizes the decrease in the relative velocity of the colliding bodies. When struck by steel bodies R = 5/9 =0,5.In the case of considering the task, you can take R = 5/9; m_2 = 2 кг; m_2^{ii} = 0, 12 kg (for the PP-63 perforator).

When carrying out calculations for a drilling rig, it is necessary to correctly take into account the value m_1, it can be large enough for deep wells.

In the monograph [66], the following formula was obtained for determining the duration of the bounce of three bodies

$$t_{dp} = \frac{1+R}{h_1+R} \cdot \frac{S}{V} \qquad (2.21)$$

where the characteristic number hi is the larger root of the characteristic equation:

$$h^2 + \left[2R - \frac{m_1 m_2^{\prime}(1+R)^2}{(m_1+m_2^{\prime\prime})(m_2^{\prime\prime}+m_2^{\prime})}\right]h + R^2 = 0 \qquad (2.22)$$

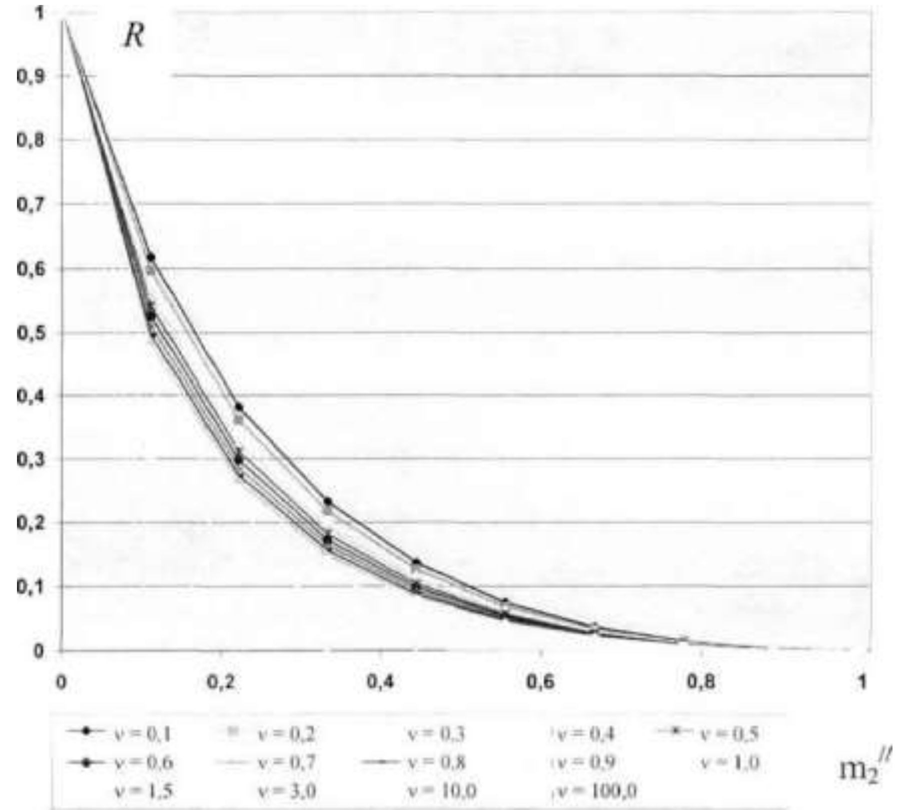


Fig. 2.4. A parametric graph of the ratio of the coefficient of recovery of the speed Y and the masses of the moving parts V (V = m2 / m1), which determines the condition of occurrence (zone under curves) or lack of bounce

In this case, just as before, the fulfillment of inequality (2.18) guarantees the completion of the bouncing before the time tk changes in the direction of the hydraulic force F Accordingly, within a finite time interval $t_{к} - t_{yd} + t_{dr}$ - three bodies (rod, firing pin, piston) are in contact with each other.It is also essential that in this case the final results of the motion are the same or almost the same as in the case of absolutely inelastic (plastic) collision (R = 0). In other words, the presence of repeated increasingly frequent collisions in the process of bounce development does not affect the final results of the movement and its energy characteristics. The intermediate striker in this case plays the role of an artificial "enlarger" of the impact plasticity.

Earlier it was shown that the efficiency of the impact head (perforator) for absolutely inelastic collision rio is higher than for not absolutely elastic collision r | if inequality (2.14) is satisfied. The above means that the fulfillment of this inequality guarantees the effectiveness of the installation of the striker

2.4. The case of a little boom

As already mentioned in Section 2.2, the bar in the vibration-shock mode of motion can be considered absolutely rigid if the propagation time an elastic longitudinal wave along it $T_{vol} = L_{\text{ШТ})}\sqrt{\frac{P}{E}}$ significantly less than the duration of the period of one collision T_{Y}d. If these values are comparable with each other, then the model of an absolutely rigid bar turns out to be inapplicable and its longitudinal vibrations must be taken into account.

We will assume that the bar is a homogeneous rectilinear bar. Longitudinal vibrations of this rod consist of the superposition of a theoretically infinite number of harmonic components with natural frequencies determined by the formulas.

In this case, the bar can be modeled as a weight on a spring, and this dynamic model of impact interaction is presented in the form shown in Fig. 2.5.

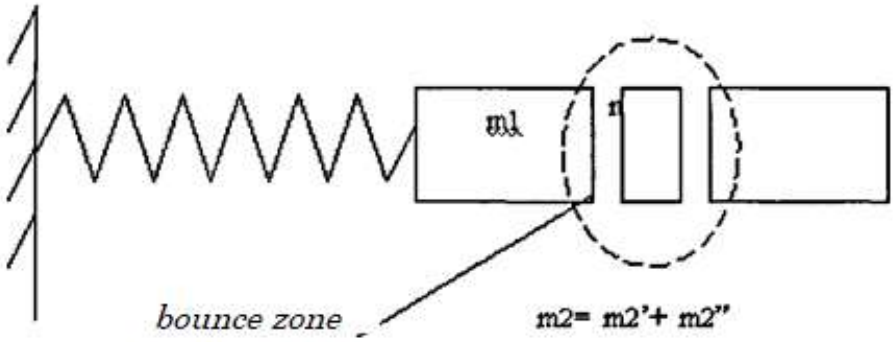


Fig. 2.5. Mechanical-mathematical model (simplified diagram) of interaction hammer piston with rod

The actual shape corresponding to the oscillations on the untertone is monotonically increasing as the cross section approaches the free end. In other words, the most intense vibrations are performed by the sections of the bar directly adjacent to the impact interaction surface. In this case, as before, the mass of an absolutely rigid body m_1 should be taken equal 1/3 $m_{\text{шт}}$ [11]. In this way, and consequently, the coefficient of stiffness of the springs $c=m_1\lambda_1^2$.

Let us now assume that the collision of the rod and the piston is not absolutely elastic and therefore their velocities immediately after the collision are determined by formulas (2.4-2.7). The subsequent law of elastic vibrations of the rod based on the introduced simplified model is determined by integrating the differential equation

$$\lambda_1 = \sqrt{\frac{c}{m_1}} \qquad m_1x+cx=0 \qquad \textbf{\textit{(2.25)}}$$

with the initial conditions: t = O, x = O, x = V *. The corresponding oscillation law has the form

$$x = \frac{V_1^+}{\lambda_1} \sin \lambda_1 t. \qquad (2.26)$$

The longitudinal elastic force transmitted by the rod to the rock is therefore equal to

$$F = cx = \sqrt{cm}V^1 + sin\lambda_1 t$$

Let us now assume that the impact is absolutely inelastic (plastic) and, therefore, immediately after the impact, the rod and piston move together. Then, with the same degree of accuracy, one should use instead of (2.25) equation

$$(m_1 + m_2)\, x + cx = 0 \qquad \mathbf{(2.28)}$$

We have additional forces acting in this case on the piston, which is neglected here. Integrating this equation under initial conditions t = 0, x = 0, x = =V, we get the law of oscillations in the form V^+

$$\mathbf{x = \ sin\lambda_0 t} \qquad \mathbf{(2.29)}$$

Where

$$\lambda_0 = \sqrt{\frac{c}{m_1 + m_2}} = \sqrt{\frac{m_1}{m_1 + m_2}}\lambda_1 \qquad \mathbf{(2.30)}$$

This movement reaches its maximum value in the next moment $t = \pi / (2\lambda_0)$. The corresponding maximum value of the force transmitted by the rod to the rock is determined by the formula taking into account (2.11) and (2.29)

$$F_{max}^{(0)} = \frac{\pi m_2 V}{l_{um}} \sqrt{\frac{m_1 E}{\rho(m_1 + m_2)}} \qquad (2.31)$$

2.6. Comparison of transmitted pulses for single and dual impacters

The compression-tension rod, along with the crown, can be represented for simplicity as a spring weight. The mass of the load t1 should be taken equal to one third of the mass of the rod, and the stiffness coefficient springs

$$C = \frac{Es}{L} \qquad (2.33)$$

where E -is Young's modulus,

S - is the section of the rod,

L- is the length of the rod with the crown.

We will assume that the impact of the striker with the barbell is not absolutely elastic in nature with the velocity recovery coefficient Rэ (0;1) [58]. Assuming that the bar is motionless before the impact, we obtain the following expression for the post-impact velocities of the bar and the striker:

$$V_1^+ = \frac{m_2(1+R)V}{m_1 + m_2}, \qquad V_2^+ = \frac{(m_2 - m_1 R)V}{m_1 + m_2}, \qquad (2.34)$$

here V - is the pre-impact velocity of the striker, and its mass.

The subsequent law of vibration of the rod is determined by integrating the equation $\boldsymbol{m_1 x + cx = 0}$ under initial conditions: t = 0, x = O, x=0, $\boldsymbol{x = V^*}$ get

$$x = \frac{V_1^*}{k_1}\sin k_1 t, (k_1 = \sqrt{\frac{c}{m_1}}) \tag{2.35}$$

The elastic force, which is transmitted by the barbell to the rock, is equal to $F = cx$.

We calculate the momentum J of the force for half the period of rotation of the rod 0 < t < π/k.

After integrating the expression, we get

Let us now assume that the impact is absolutely inelastic (R = 0). After the collision, the rod and the striker "stick together", moving to the bottom with a general speed. In this case, the pneumatic force of pressure P directly acts on the rod through the striker. Therefore, the equation of the subsequent movement of the striker and the rod has view:

$$(m_1 + m_2)\ddot{x} + cx = P. \tag{2.37}$$

Integrating this equation under initial conditions t = 0, x = 0, $x = V^*$, get

$$x = \frac{V^*}{k}\sin kt + \frac{P}{c}(1 - \cos kt), \quad k = \sqrt{\frac{c}{m_1 + m_2}} \tag{2.38}$$

Determine the basis (2.38) momentum J elastic force F = cx for half-cycle oscillations 0 <t <П / k:

$$J = 2m_2 V + \pi P\sqrt{\frac{m_1 + m_2}{c}} \tag{2.39}$$

Pulse difference J and J1, according to (2.36) and (2.39), will be

$$J - J_1 = 2m_2 V\frac{m_2 - m_1 R}{m_1 + m_2} + \pi P\sqrt{\frac{m_1 + m_2}{c}} \tag{2.40}$$

This value is positive in a wide range of variation of the system parameters. В частности, always J > J1 at $m_2 > m_1 R$. In all cases, it can be argued that the effective force transmitted to the rock during plastic impact will be greater. Accordingly, the drilling process will be more efficient. In this case, in the process of rapprochement of the striker and the rod, the onset of bounce is very likely. As a result, after a certain finite time, "sticking together" of all three bodies occurs. In other words, the result of the motion is as if the collision were plastic. That is, the proposed design of the striker-striker-rod percussion system makes it possible to “make” the percussion interaction quasi-plastic and, thus, to increase the drilling efficiency.

2.8. Conclusions from theoretical research

1. It has been established that the excess of the impact force during a quasi-plastic impact (the velocity recovery coefficient is equal to zero R = 0) in the "rod-striker-piston" system over the same force with a partially elastic impact (R> 0) in the "rod-piston" system , will take place when the condition $m_2 > m_1 (2R + R^2)$ is fulfilled, which shows the effectiveness of using the striker as a means to achieve an increased impact efficiency.

1. 2. Fulfillment of the ratio $m_2 > m_1$ (2R + R2) is a criterion for calculating the rational parameters of the striker, since it determines the excess of the transmitted energy from the piston to the rod during quasi-plastic impact compared to a partially elastic one.

2. A method for calculating a double striker has been developed, which allows one to describe the conditions for the occurrence of bounce (quasi-plastic impact), which increases the impact efficiency by at least 15%.

3. The effect of shock load damping for a DTH hammer is analytically established when elastic elements are installed in front of the piston, the force, duration of the impact and the main parameters of which are described by a parametric differential equation, and the regulation of the shock pulse parameters allows obtaining an increase in drilling speed and bit life.

4. A dynamic model of a submersible striker is developed, expressed by a system of nonlinear differential equations, taking into account: damping coefficient, pressure value, piston cross section

3. LABORATORY AND BENCH STUDIES OF DUAL IMPACT SYSTEMS

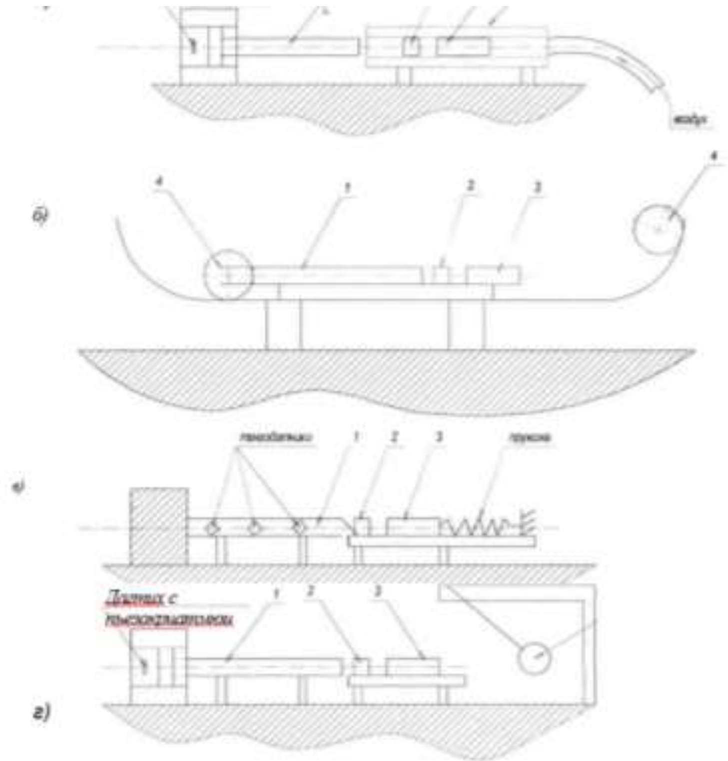
3.1. Statement of the experimental study problems

In accordance with the goal and tasks set in the work, it was necessary to carry out the following laboratory and bench studies to confirm the selected hypotheses and theoretical calculations:
- substantiation of the design of the laboratory facility;
- determination of the parameters of the strike system, the calculation of the ratio of the masses "striker-striker";
- determination of the parameters of the bounce process and the ratio of impulses transmitted by the shock system to the bar for single and double strikers;
- preliminary tests of the developed stand design;
- carrying out tests using strikers made of various materials;
- carrying out tests using strikers made of different materials, installed at different initial distances from the rod;

processing of the received oscillograms, their spectra and differential and integral transformed types;
- analysis of the results of laboratory and bench experiments.

3.2. Laboratory studies of two-mass impactors

The most effective means of determining the parameters of collision of bodies are laboratory and bench studies. To carry out these studies, several variants of stands were considered, the diagrams of which are shown in Figure 3.1



The diagram shown in Figure 3.1 (a) has an analogue: SUIP (universal stand for the study of perforators, designed by the Gipronickel Institute [49]). This stand allows you to determine the parameters and characteristics of the impact with a high degree of accuracy. This installation uses an industrial rock drill with a load cell connected to the shaft. Here the conditions are as close as possible to the real work of the perforator and therefore this stand is preferable, but the creation of such a stand is a rather laborious process and requires relatively large material costs.

In the work of Gorin A.B. [30] a stand is being considered for researching a high-power hydraulic hammer, however, measurements of the main parameters at this stand are made by pressure sensors, which is impossible when examining pneumatic drill heads. The layout of the stands shown in Figure 3.1 (c, d) has the following disadvantages: the complexity of taking measurements with glued strain gauges or sensors based on piezoelectric crystals, the design of imparting initial energy to the striker in the form of a spring or a suspended ball is not rational as it requires large dimensions of the installation and it is difficult to obtain a fixed impact energy.

The diagram in Figure 3.1 (b) is a structure of two guide grooves and supports along which balls 30 mm move, and supports on which a rod 10 mm and a piston-impactor 10 mm are located. A more detailed drawing is shown in Figure 3.2.

To transfer the full impact energy, it is necessary that all colliding parts are strictly oriented in space (have one longitudinal axis), this can be done by the following means:

1.Variant - centering the suspension on the thread. The colliding parts (rod, firing pin and striker) are suspended from the frame located above the colliding bodies with the help of threads. The disadvantage is that the colliding elements vibrate in the horizontal plane and cannot be eliminated.

2. option - centering with a needle. A hole is drilled in the center of the rods along the longitudinal axis, into which a guide needle is inserted and the striker moves along it.

3. Option (adopted for the experiment) - centering by a chute. In the groove, as shown in Figure 3.2, the bar, the striker and the striker are placed. Two types of gutters were used: glass and polymer.

We used rods with a diameter of 10 mm, the length of which was chosen from the mass ratio according to the graph in Figure 2.4: Lsht = 270 mm, Lud = 71 mm, La = 9 mm.

The laboratory research methodology at the facility, according to Figure 3.2, is as follows.

The ball 4.1 rises to a height L, rolls freely along the chute and strikes the striker 3, which transfers part of the impact to the striker 2. The striker strikes the bar 1, rebounds and hits the striker again, etc. until the striker, firing pin and rod touch. At this moment all three bodies "stick together". The impact energy from the bar 1 will be transferred to the ball 4.2 and it rolls back to a height

The next stage of research consists in using a solid striker instead of a striker with a striker. The methodology for the second stage is exactly the same as in the first stage. In this case, the ball 4.2 will roll back to a height br. Knowing the difference in heights br and t, one can find the increment in height (energy transferred to the bottomhole) when using a two-mass piston-striker.

When the bounce effect occurs, an increase in g | Impact by 20h-50% should be observed. Due to the low mass of the striker, high air resistance and high friction force, the values obtained experimentally and theoretical data differ significantly. The bounce effect in this case cannot be clearly recorded.

To reduce the friction force of the striker against the chute and the force of resistance to the movement of the striker due to air compression in the tube, the striker was replaced by a ball of the same mass. In this case, the sliding friction force is replaced by the traction force rolling and reduced air resistance.

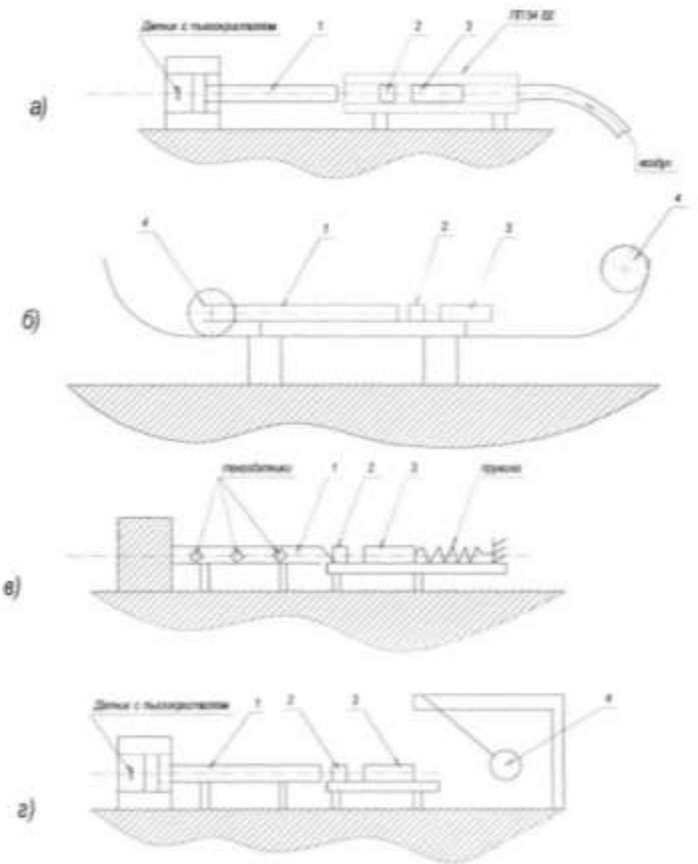
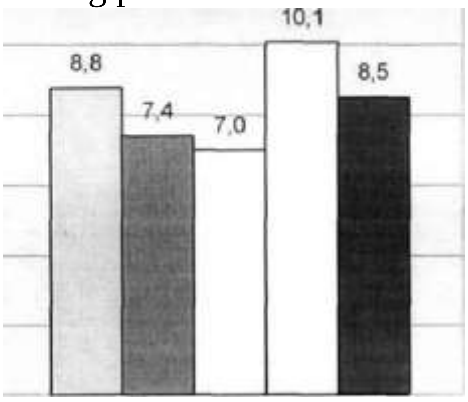


Fig. 3.2. Laboratory stand layout: 1 - barbell; 2 - striker; 3 - drummer; 4.1 - ball I; 4.2 -ball 2; 5 - glass tube-gutter

In fig. 3.3 and fig. 3.4 along the Y-axis is the distance in divisions by which the ball will rise 4.2. One division is equal to 5 mm. As can be seen from Fig. 3.4 when replacing the firing pin-cylinder with the firing pin-ball, the energy transmitted to the ball 4.2 increased (positions "firing pin in the form of a ball a = 1 mm" and "firing pin in the form of a cylinder a = 1 mm"). The energy transmitted to the ball 2 depends on the distance from the striker to the end of the rod. The larger this distance, the less impact energy is transferred to the bar (positions "firing pin in the form of a cylinder a = 1 mm" and "firing pin in the form of a cylinder a = 5 mm1 '). But at the same time, the energy upon impact of the two-mass system turned out to be less than from impact As can be seen from Figure 3.4, the energy at the impact of the two-mass system on the fixed rod turned out to be close, and in some tests it was even observed that the impact energy was exceeded by the solid striker (positions "firing pin in the form of a ball a = 1 mm" and "large striker.



▫ □ Ball firing pin a =1 мм
▫ □ cylinder-shaped firing pin a=1мм
▫ □ cylinder-shaped firing pin a = 5 мм
▫ Big drummer ■ small striker without striker

When comparing the results of laboratory studies shown in Figures 3.3 and 3.4, it can be concluded that the impact energies of a solid striker and a two-mass system when hitting a fixed rod are approximately equal, however, it was difficult to visually estimate the distance with great accuracy. To avoid measurement errors, it is necessary to improve the measurement quality by using sensors that record the passage of the shock pulse along the rod.

For this, in the laboratory of public use "Dynamics" at the department "Theory of elasticity" of St. This setup is discussed in more detail in Fig. 3.5.

3.3. Board studies of impact systems "impact-fighter-board"

To simulate the processes of collision of a striker with a barbell with parameters similar to those that arise during the operation of a perforator, a setup was created, the block diagram of which is shown in Fig. 3.5. The steel piston (2) was accelerated by a pulsed magnetic field of a solenoid (b) placed on a stainless steel pipe (1), at the end of which a steel rod (3) with a diameter equal to the piston diameter was fixed.

A pulsed magnetic field in the solenoid was excited when the capacitor bank (C) was discharged through the thyristor (7), when a control voltage pulse was applied from the generator (6).

The piston speed could be changed by changing the voltage of the capacitor charge. The piston was accelerated at a distance of 5-8 cm. The speed was measured by the electrocontact method through the windows (8). The measurement error did not exceed 2% [89, 90].

The speed of the steel piston, with dimensions 24x200 and an axial hole of 8 mm, could reach 15 m / s when the capacitor bank was charged up to 900 V.

Sensors D1 and D2 were placed on a composite rod-bar. Sensor D1, for measuring longitudinal vibrations, was placed at a distance of 233 mm from the loaded end of the rod-rods, at the junction of the rods.

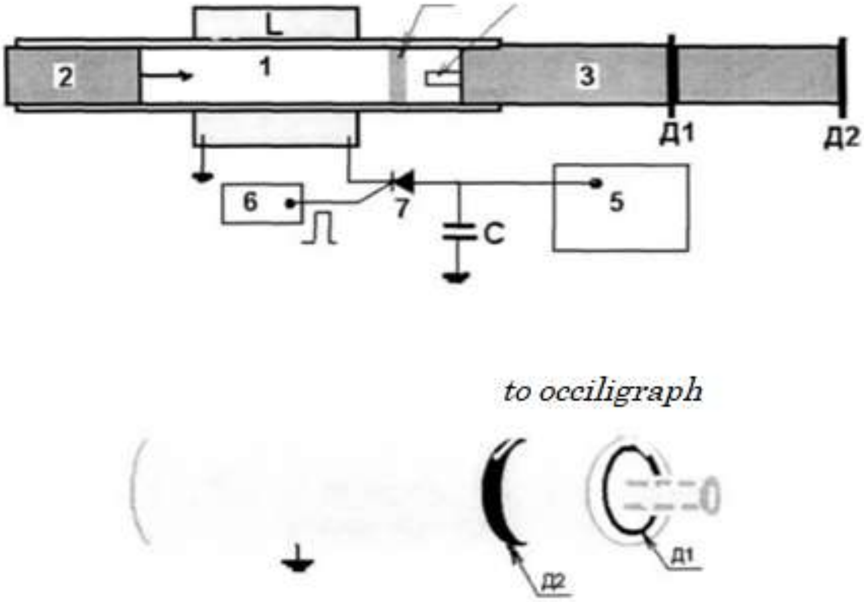


Fig. 3.5. Block diagram of the experimental setup (assembly assembly at the bottom - photo) I - barrel; 2 - piston; 3 - rod (rod 24x500mm): 4 - striker; 5 - constant voltage source (up to u = 1000 V); 6 - pulse generator; 7 - thyristor; 8 - window for speed measurement; C - capacitor bank (C = 800ткР); B - solenoid (b = 15mH); D1 and D2 - piezo sensor.

The second part of the rod 699 m long was rigidly connected to the first segment of the rod using a threaded connection (M12x1.25mm). A sensor D2 was placed on this part of the rod, recording transverse vibrations in the rod during the passage of a shock pulse. D2 - located at a distance of 30 mm from the junction of the rods, that is, at a distance of 263 mm from the loaded end of the rod.

Both sensors are made of piezofilm - GTVDF. D1 - made in the form of a disc, 100 μm thick, 24 mm in diameter with a central hole of 12 mm, the current collection from the piezoelectric sensor was carried out using copper current collectors 50 μm thick. D2 - made of piezofilm 30 microns thick and made in the form of a strip 2 mm wide and 70 mm long. Current collection was carried out with a copper strip 50 μm thick. The sensor width, which determines the temporal resolution of the sensor, made it possible to register elastic vibrations with a resolution of no worse than 0.5 μs.

The electrical signal from the sensors is proportional to the displacement of the surface with which they have acoustic contact (on which they are located):

$$V (t) = k-u (t),$$

where V (t) is the electrical voltage taken from the sensor;

k - coefficient determined by the sensitivity of the sensor;

u (t) - movement of the controlled surface.

The pressure in the rod in an elastic wave, as is known, is equal to:

$$P(t) = \rho \cdot c \cdot v(t),$$

$$\sigma_{max} = \rho \cdot c \cdot 0{,}5 \cdot V_{уд}, \qquad (3.1)$$

Where P-is the density, c is the speed of sound,

v (t) is the mass velocity of the particles [v (t) = du (t) / dt],

σmax is the amplitude of the voltage pulse,

Vud is the speed of the piston.

Thus, the time dependences of the force parameters of the impact are proportional to the derivative of the time variation of the electrical signals of the sensors.

In fig. 3.7 shows typical oscillograms corresponding to the impact of the piston on the rod. Upon impact by a single piston, a smooth pulse is observed on the oscillogram, followed by pulses corresponding to elastic waves reflected from the ends of the rod. Figures 3.7 a and 3.7 b show oscillograms of electrical responses from sensors D1 and D2, which recorded longitudinal and transverse displacements, respectively, scales along the Y axis are indicated in volts. Comparing the graphs in Fig. 3.7 a and 3.7 6 it can be seen that they show identical wave patterns, in which there is a complete coincidence of both minima and maxima, as well as the coincidence of characteristic points both in the time scale and in the amplitude. This indicates a reliable recording of the time dependences of elastic waves in the rod by both sensors.

It can be seen that, in contrast to the smooth pulse corresponding to the piston impact, the presence of an intermediate striker-striker leads to the appearance of bursts on the oscillograms ahead of the main pulse corresponding to the combined action of the piston and striker.

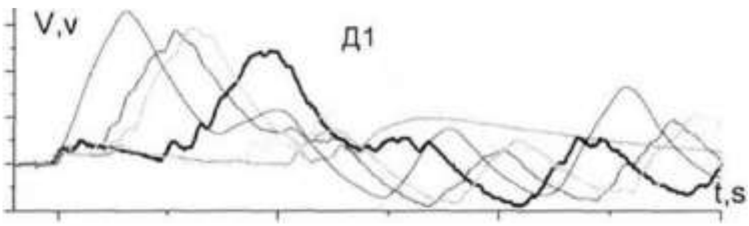


Figure 3.8. Oscillograms of signals from sensors D1 and D2 for the case of collision of a piston with an intermediate striker and a rod at different initial distances of the striker from the end of the rod Black oscillograms correspond to the impact of the piston only, all color oscillograms correspond to the impact of this the same piston with a striker t 71

Oscillograms shown in Fig. 3.8, after enlargement and division into three graphs in one figure are presented in Fig. 3.9 c, 3.9 d and 3.9 d.

Figures 3.16 and 3.17 show the dependences of the integral values on the shock impulse for various values of the initial positions of the striker relative to the end of the rod when approximating the integration intervals within the range: 1 (r) = 2100-1000 / r0'1.). The calculated value of the shock impulse upon impact with a single piston is 4300 Pa * B. The energy of a family of shock pulses at the impact of a piston with a striker is 10- ^ 20% higher than this indicator at an impact with a solid piston. Also, the amplitude of the first pulses in a family sometimes exceeds the amplitude of a single piston impact.

Figure 3.18 shows the most typical graph of the dependence of stresses in the rod when using a striker made of different materials, from which it can be seen that the use of light strikers (for example, titanium) allows you to obtain the most advantageous family of pulses, consisting of three or more bursts, and the amplitude of the maximum burst exceeds the amplitude of a single piston impact.

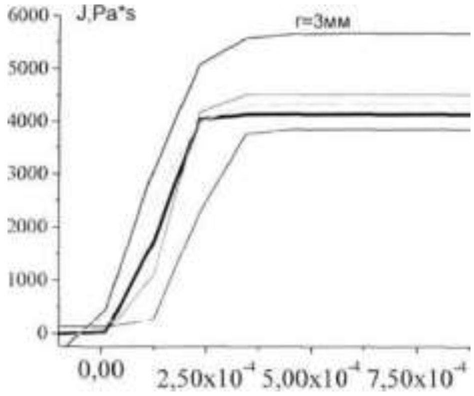


Fig. 3.16. Change of integrals of impulse voltages for different cases collisions

Results of stand tests of the "impact-fighter-board" systems

Analysis of the results of laboratory and bench tests of shock systems (graphic material - Fig. 3.6-3.18) on the propagation of shock impulses in the rod, recorded by the sensors of the installation, shows:

- it has been experimentally proved that the impact of a piston-impactor in the case when the firing pin is located between the rod and the piston gives a family of "L-shaped" impulses, the total energy of which exceeds the energy of the bell-shaped impulse from the impact of a conventional piston of equal mass.

an impact by a solid piston gives a classic so-called "bell-shaped" impulse, and the speed of the piston at the moment of impact can vary in the range of 2-14 m / s, and the magnitude of its rebound depends only on the force applied from the side of the solenoid coil;

the piston-striker starts to move under the action of a force, the nature of which is fundamentally different from the action of hydraulic (pneumatic) force, however, the effect of bouncing when the piston strikes through the firing pin has always been observed;

"L-shaped" impulses are close in shape to the "ideal" impulse obtained as a result of computer simulation by K.I. Ivanov [2];

the energy of the family of shock impulses at the impact of the piston with the striker and the amplitude of the first impulses in the family is 10–20% higher than these indices for the impact with a solid piston;

the passage of the shock pulse along the length of the rod and the quality of the impacts cause superposition and distortion of the impulses reflected and re-reflected from the ends of the rod;

for crystalline soft and medium hard rocks, in which the resistance to shearing is much lower than the resistance to compression, and in the case of using drill heads with independent shock and rotational mechanisms, taking into account the hypothesis of destruction at the leading edge of the shock pulse, a significant increase in the efficiency of rock destruction should be expected;

in the shock system, in which the piston-striker is divided into a large (piston) and a smaller (firing pin) part, a total shock impulse of adjustable amplitude and duration is formed, consisting of at least three bursts (sub-impulses), the parameters of which are controlled by changing the distance between the rod and brisk;

the relationship between the clearance of the striker-rod and the following parameters of the striking system was experimentally established: amplitude, number of bursts, total pulse energy, and the bounce effect is most clearly manifested at gaps of less than 5 mm between the striker and the rod.

4. DEVELOPMENT AND INDUSTRIAL TESTING OF ADVANCED DRILLING TOOLS

4.1. Formulation of problems for industrial testing of new drilling means

In accordance with the purpose and objectives of the research, it is necessary to carry out the following works:

- development of the design of a portable rock drill with a dual impact system;
- development of a program and methodology for testing portable rock drills of modernized designs;
- development of the design of a drill with an over-bit striker for the SBSh-250 machine;
- production of a prototype of a pneumatic hammer and testing it;
- analysis of the results of mine tests and the formulation of requirements for the design of improved rock drills and hammers;
- development of a methodology for calculating the economic efficiency of the introduction of new drilling tools.

4.2. Research of portable punchers with improved impact system

The design of telescopic rock drills is based on an impact-rotary principle of action with a valve air distribution system and a rear-mounted drill rod rotation mechanism. Unlike portable, domestic telescopic hammer drills do not have a drill holder. Telescopic perforator PT-63 of the Pnevmatika plant consists of a perforator body 1111-63 and a telescopic feeder located coaxially with it. Air distribution is carried out by a flat ring valve. The shock-rotating mechanism includes a ratchet mechanism, a helicoidal rod and a piston-striker with a rod and a helicoidal nut. Rotation of the drill rod occurs during the return stroke of the hammer piston, coupled with the axle box, equipped with a hexagonal socket for the drill rod shank.

The disadvantages of drilling with PT-63 perforators are mainly associated with the peculiarities of drilling apatite-nepheline ores. The PT-63 perforator has a high impact energy, which it transfers to the cutting tool. Applying a single blow with a high energy leads to increased wear (dullness) of the cutting tool. Sometimes, when drilling with a perforator in a rock with a lower strength coefficient, the application of such a powerful single blow leads to a complete stop (jam) of the cutting tool. The improvement of the design of portable telescopic perforators proposed by the author together with the specialists of the Pnevmatika plant consists in the development of modernized percussion systems of two-mass percussion hammers for such perforators, which are called PPT-63 (see Appendix).

The technical characteristics of the PT-63 and PPT-63 rock drills are shown in Table 4.1.

Table 4.1-Technical characteristics of PT-63 and PPT-63 rock drills

Name	ПТ-63	ППТ-63
Weight, kg	63	60
Impact frequency, s'1	>98.5	>63.74
Torque, Nm	>38.4	>30
Air consumption, m 7min	>5.8	>26.93
Feed stroke, m	>0.65	>0.65
Sound level, dBA	117	111
Drilling depth, m	<5	<5
Coef. rock fortress,	<20	<20

Data on various weights of pistons of impactors of various modifications (which were tested in production conditions at the mine) are summarized in Table 4.2.

Table 4.2-Weights of pistons of strikers in different modifications of PP-63

Name	Mass of pistons-strikers, kg.
ПП-63	2,020
ППТ-63	1,875 + 317 = 2,192
ППТу-63	2,020 + 317-196 = 2,141

4.2.1. Testing of perforators PP-63 (PPT-63, PPTu-63) with improved shock system

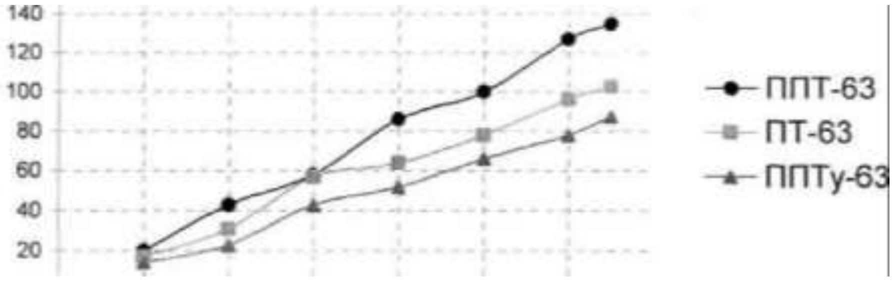
1.04.2002 at the Kirovsky mine of the mountains. +252 m, studies were carried out aimed at determining the drilling speed of perforators of various modifications. Figures 4.1 and 4.2 show photographs of a disassembled percussion system and a PPT perforator at the bottom of the Kirovsky mine.

4.2. Units of the disassembled PPT perforator: pistons, strikers, striker

In the course of the experiment, measures were envisaged to ensure the reproducibility of drilling conditions with perforators:

- the emphasis of the pneumatic support in the working soil was made from wooden ladders, which excludes slipping of the pneumatic support;
- new sets of drill rods made of alloy steel KTSh-40 crowns (three-point);
- the holes were drilled at an angle of 80 °;
- the perforators were connected to a single pneumatic system, the pressure during the test, according to the pressure gauge readings, was P = 0.5 MPa;
- preliminarily, drilling was carried out in the rock to a depth of 1W = 75 mm.

The results of the experiments are summarized in table 4.3, according to which graphs are built (Fig.4.3)



O 100 200 300 400 500 600 700

Hole length, mm

Table 4.4-Perfarators parameters

Name		ПТ-63					ППТ-63					ППТу-63				
№ trials		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Drilling time	Borehole length 200мм	32.4	33.6	34.3	32.8	33.0	40.0	39.0	41.0	40.5	40.3	26.0	27.5	24.9	25.6	25.8
	Borehole length 400мм	35.0	34.1	35.2	33.6	34.8	41.2	43.0	40.5	42.4	43.6	27.3	26.1	26.8	27.0	27.3
	Borehole length 650мм	35.6	33.3	34.5	36.6	34.2	53.8	52.0	54.5	52.1	50.1	31.7	36.4	35.3	35.4	32.9
Total time of drilling a hole, s		103	101	104	103	102	135	134	136	135	134	85	90	87	88	86
Average drilling time, s		102.6					134.8					87.2				
Drilling speed, s		6.31 | 6.44 | 6.25 6.31 6.37					4.81 | 4.85 4.78 | 4.82				4.85	7.64 7.22		7.47 | 7.39 7.56		
Average drilling speed, s		6.34					4.82					7.45				
Hardness coefficient of rocks.		16														
Drilling speed standard deviation.		1.14					0.83					1.34				

As can be seen from the graphs, the standard deviation of the drilling speed is significantly lower than the changes in the drilling speed.

The number of parallel experiments in one drilling series was determined using parametric planning by the iterative method [39, 43]. Reproducibility was determined by the homogeneity of dispersions using the Cochran test. For this, according to the preliminary data of one experiment, consisting of N0 series and then parallel experiments of drilling in a series, the calculated value of the Cochran's number in was determined, then it was compared with the tabular OCR corresponding to the degrees of freedom of the conditions of the series. If in <Ocr - the variances turn out to be homogeneous, and the hypothesis about the reproducibility of the experiment is accepted. If O> Okr, then it is necessary to increase w and repeat the comparison of criteria.

Table 4.4 summarizes the data for calculating the reproducibility of measurements of the drilling time, from which it can be seen that for the obtained values of variances and w = 5, the experiment is reproducible. The analyzed series of experiments is characterized by the maximum values of variances, therefore, for other experiments, 5 parallel experiments in a series are sufficient.

Table 4.4

	Borehole depth, mm	Drilling time, s	Y_{cp}, H	S_v^2	$S^2_{v\,max}$	G	GKP	Note
1	120							
2	125							
3	120	20	120	12				
4	115							
5	120							
1	250							sh=5
2	250							к=3
3	260	40	255	25	95	0,719	0,746	Я=0,05
4	260							
5	255							
1	325							
2	330							
3	340	60	337	95				
4	350							
5	340							

Processing the results of experimental studies allows us to draw the following conclusions:

The presence of a striker in the design of the perforator made it possible to increase the drilling speed from 4.82 mm / s to 7.45 mm / s, that is (by 35%) in relation to PPT-63 to PPTu-63; and from 6.34 mm / s to 7.45 mm / s by (15%) in relation to PT-63 to PPTu-63.

Drilling with a hammer drill with a PPTu-63 striker (with a lightweight piston striker) allows to increase the impact energy by increasing the speed of its movement with an increased stroke.

When synchronizing the work of the striker and the piston of the striker, debugging the patented design of the modernized rock drill [73] as a whole, when used on rocks with a high content of apatite, it will provide an opportunity to further increase drilling productivity. Moreover, productivity growth can exceed 35%.

Testing of the Tula SSPB perforators with an improved percussion system

In accordance with the order of the technical director of JSC Apatit (see Appendix) on July 11, 2003, at the surface complex near the mechanical shop of the Kirovsky mine, studies were carried out to determine the drilling speed of the modernized and factory Tula perforators SSPB.

The drilling was carried out in a monolithic lump of apatite ore delivered from a quarry. According to the data presented by the mine surveying service of the Kirovsky mine, the hardness of the rocks was G = 14.

Test procedure

The tests were carried out in 3 stages.

Stage 1. Testing the SSPB rock drill with a standard piston.

Stage 2. Testing of the SSPB perforator on pneumatic support with a standard piston-hammer..

Stage 3. Testing of the SSPB perforator on pneumatic support with a split percussion system (piston-striker-firing pin). The mass ratio is selected according to the parametric graph (Figure 2.4). The perforator operation scheme is shown in Figure 4.4. In fig. 4.5 and 4.6 show details and assemblies of a perforator, as well as a general view of drilling a lump of apatite.

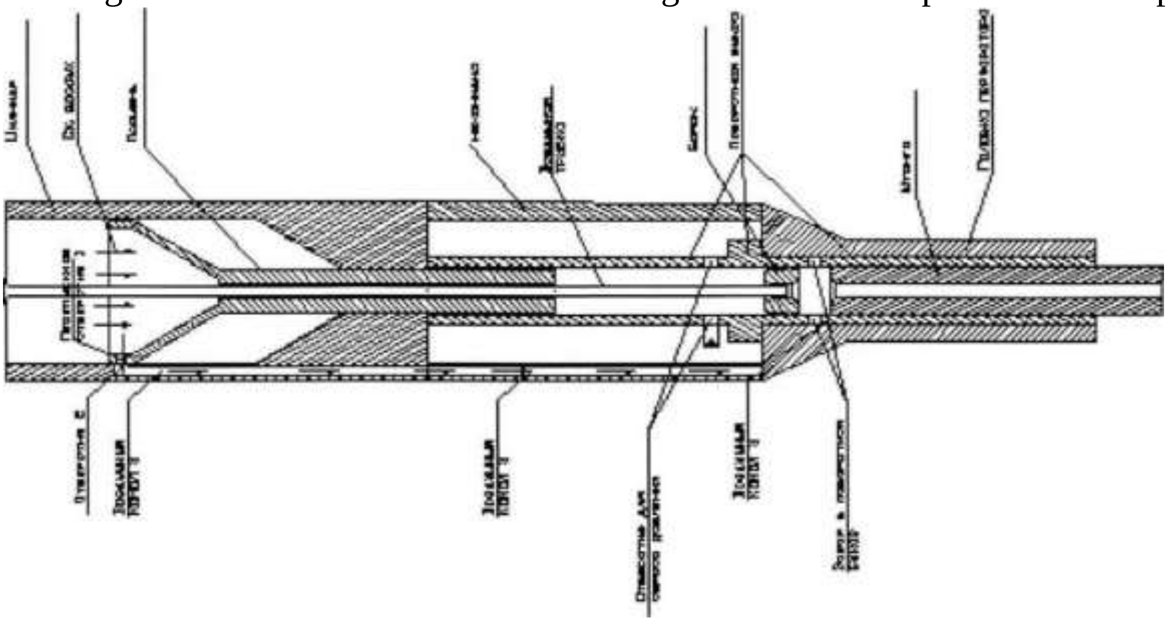


Fig. 4.4. The scheme of work of a portable hammer drill with an upgraded percussion system.

In the course of the experiment, additional measures were envisaged to ensure reproducibility of drilling conditions with perforators:

- drilling was carried out on a homogeneous rock sample of constant composition and a given strength indicator;
- the emphasis of the pneumatic support in the soil was made from wooden ladders, at the same angle of inclination; during drilling, the axial force on the perforator was transmitted only from the pneumatic support;
- new sets of drill rods made of alloy steel st. 28KhNZM and new chisel bits;
- in a series of experiments, drilling was always carried out by the same drillers who had undergone special instructions.

Experimental results.

Trial drilling was carried out with a hammer drill, with a striker made of 40X steel with a 45 ° bevel (see the drawing in the Appendix). Boreholes were drilled with a depth of 250 mm (without drilling), not with a drill rod at a pressure in the pipeline of 0.62 MPa. The following data were obtained: 1- <drill - 250 mm, ^ = 104 s, Ubur = 2.4 mm / s, which is 10% (10.95%) more than the drilling speed with a factory perforator (2.17 mm / s).

Compared to the initial results, the drilling speed increased by 22% (with a standard piston drilling speed of 2.17 mm / s). Damage: deformation of the striker on the rod side (there is almost no deformation on the piston side), slight abrasion of the air tube. The wear of the strikers was different, from crumbling to strong heating.

4.2. Research of economic efficiency of the use of drilling equipment

4.2.1. Assessment of the prospects for using domestic drilling equipment at JSC "Apatite".

The term "innovation" in relation to industrial"

the enterprise designates an event of scientific and technological progress (mechanization, electrification, automation, modernization of technical means or their replacement with fundamentally new ones, the use of more advanced substances and materials in the production process, as well as the improvement of the organization of production and labor), aimed at increasing production efficiency. Thus, the modernization of drilling equipment is just such an innovation. In the future, the abbreviation PRS (Improvement of Drilling Facilities) will be used.

The implementation of innovations or PRS in production solves not only purely technical, organizational and economic problems, but also social and environmental ones, which include: improving working conditions, increasing the level of its safety and comfort, recycling production waste, increasing the level of environmental safety, etc. ... The solution of at least one of these tasks makes the implementation of the innovation economically and socially effective.

The decision on the feasibility of implementing the innovation (organizational and technical solution) is made on the basis of the economic effect calculated for the billing period (the so-called integral economic effect).

The integral economic effect is the excess of the total results for the calculation period from the implementation of the innovation over the costs of its implementation. In this case, both results and costs are reduced to the same time period, i.e. discounted:

As the results, the amount of cash receipts in the form of an increase in profit and an increase in depreciation deductions is considered.

The effectiveness of an innovation is understood as the ratio of the effect and the costs that caused it. The efficiency assessment is based on the following basic principles:

- consideration of the innovation throughout the entire period of its implementation and functioning (life cycle);
- modeling of cash flows, including all cash receipts and expenses related to the implementation of the innovation for the billing period;

comparability of conditions for comparing various options for innovations;

- the principle of positiveness and maximum effect - the effect of the implementation of the innovation must be positive; when comparing several alternatives, preference should be given to the one with the greatest effect;
- taking into account the time factor;

- taking into account only the forthcoming costs and results - the previously created resources used in the implementation of the innovation are estimated not by the costs of their creation, but by the alternative cost, based on the best possible use of them. Past costs that do not provide the possibility of obtaining alternative income in the future (i.e., obtained outside this innovation) are not taken into account in cash flows and do not affect the value of performance indicators;

the assessment of the effectiveness of the measure should be made by comparing the situations “with innovation” and “without innovation”, and not “before the innovation” and “after the innovation”;

- taking into account all the most significant consequences;
- taking into account the impact on the efficiency of the need for working capital (taking into account the "stable" liabilities;
- taking into account the influence of inflation on changes in prices for various types of products and resources during the period of implementation of the innovation;
- taking into account the influence of uncertainties and risks accompanying the implementation of the innovation.

Indicators of economic efficiency of investments

Net present value (NPV) is the accumulated discounted effect for the accounting period. It characterizes the excess of total cash receipts over total costs for this innovation, taking into account the time factor.

The return on investment index (ID) characterizes the return on investment and is defined as the ratio of the sum of the discounted elements of the cash flow from operating activities to the absolute value of the discounted sum of the elements of the cash flow from investment activities.

In economic practice, two methods are used to calculate the payback period of an investment. The first method is used at the preliminary stage of assessing the economic efficiency of investments and interprets the payback period as the period for which the amount of income received (the amount of depreciation and profit after tax) is equal to the amount of investment.

The second method is based on the discounting procedure, when investment income is reduced to the current point in time using discount coefficients. In accordance with this approach, the number and duration of periods (years) are determined, during which the investment funds are fully reimbursed. The shorter the period of full reimbursement of capital investments, the more effective the projects are from an economic point of view, other things being equal.

The internal rate of return (IRR) is the discount rate (Eun) at which the magnitude of the reduced effects is equal to the reduced capital investment.

Table 4.7- The structure of the prime cost of penetration of 1 m of development,%

Cost Item Name	Domestic equipment	Imported equipment
Supporting materials	61,2	11,9
Depreciation	17,3	84,8
Salary with accruals	3,8	0,6
Electricity	17,7	2,7
TOTAL	100,0	100,0

Таблица 4.8-The structure of the extraction of 1 ton of orefrom the block, %

Cost Item Name	Domestic equipment	Imported equipment
Supporting materials	83,8	36,9
Depreciation	2,4	52,5
Salary with accruals	3,6	2,5
Electricity	10,2	8,1
TOTAL	100,0	100,0

The data obtained allow us to conclude that the costs of the “Depreciation” element when using imported equipment are several times higher than similar costs when using domestic equipment.

In the future, within the framework of studies on the feasibility study of the modernization of drilling equipment, it is planned to determine the economic efficiency of the investment project for the modernization of drilling equipment in the conditions of the Kirov mine of Apatit OJSC.

The key points in determining the indicators of the economic efficiency of investments in the modernization project are:

- determination of the amount of investments in fixed and circulating assets (growth of fixed and working capital), taking into account the costs of research and development work, i.e. inclusion in the total cost of the project of the cost of R&D;

- taking into account not only the direct economic effect (in the form of an increase in profit after taxation and an increase in depreciation deductions), but also the social component of the effect (in the form of maintaining the number of jobs at Russian machine-building plants, reducing industrial injuries, etc.).

4.2.1. An example of calculating the economic efficiency of improvement mechanization of tunneling works at the Kirovsky mine of JSC "Apatit"

The indicators of the economic efficiency of the investment project are calculated in relation to the organizational and technical solution if the results of its implementation affect the final indicators of the production and economic activity of the enterprise. This applies to measures involving new construction, reconstruction, technical re-equipment, expansion of production capacity.

If the organizational and technical solution provides for the introduction of new technology, replacement of individual technological equipment, etc., then the integral economic effect from the implementation of the innovation is calculated.

As the results, the amount of cash receipts in the form of an increase in profit and an increase in depreciation deductions is considered. The increase in profit is characterized by savings from a decrease in operating (current) costs.

In general, the increase in profit from the implementation of the innovation is calculated by the formula:

$$\Delta \boldsymbol{П} = \Delta \boldsymbol{C} - \Delta \boldsymbol{O},$$

where ΔC - reduction (savings) in operating costs from the implementation of the innovation; ΔO is the increase in payments from the balance sheet profit received from the implementation of the innovation.

The reduction in operating costs is determined by the formula:

$$\Delta \boldsymbol{C} = (\mathbf{C_в} - \mathbf{C_п})\,\mathbf{Q_п}$$

where: Cw-Cn - the cost of a unit of annual production (produced minerals), respectively, in the baseline and design versions; Qn is the volume of production (extracted minerals) to which the evaluated innovation applies.

When calculating the increase in profit, it is allowed to be limited to the first year after the implementation of the proposed technical or organizational solution, i.e. determine the AP for the first year of implementation of the design solution.

The increase in payments from the balance sheet profit is determined by the formula:

$$\Delta \boldsymbol{O} = \Delta \boldsymbol{C} * \boldsymbol{Hc}$$

where: Hc - income tax rate (tax rate), unit shares.

The increase in depreciation charges from the implementation of the proposed innovation will be determined by the formula:

$$\Delta \boldsymbol{A} = \boldsymbol{A_П} - \boldsymbol{A_б}$$

where: AП and Aб - the amount of depreciation deductions for the period of implementation of technical solutions, respectively, according to the design and base case (calculated according to depreciation rates depending on the cost of new and basic equipment).

Improvement of the mechanization of tunneling operations for raising workings at the Kirovsky mine of Apatit is carried out on the basis of the use of the modernized model of the PPTu-63 perforator with a double percussion system at the KPV-4A tunneling complex. The complex consists of a self-propelled shelf, a monorail, a hose winch, a power supply, communication and lighting equipment. Drilling of boreholes is carried out from a self-propelled shelf with perforators PPT-63.

The technical characteristics of the tunneling complex are presented in Table 4.3.

Table 4.9-Technical characteristics of the complex КПВ—4А.

Indicator	Unit measurements	Value
Working slope	град.	60+90
Section of production	м'	4ч-6
Working length	м	80
Carriage lifting capacity	кг	500
Carriage speed	м/сек.	0,2
Weight	т	10,3

It is proposed to replace the PPT-63 perforator with the PPTu-63 perforator (the sample is not certified) using a modernized percussion system.

The directions of the formation of the economic effect are: increasing the annual productivity of the perforator by 40-50%; increase in the durability of KTSh-40 drill bits by 20% due to the application of a double blow.

The initial data for the calculation are presented in Table 4.10.

Table 4.10-Technical indicators for drilling equipment options

Name indicator	Unit measurements	Base option	Project option
Annual drilling volume	шп. м	432000	432000
Rotary hammer performance	шп. м/год	20650	28664
Average ROP	м/час.	17,58	27,61
Hardness coefficient of rocks	ед.	16—20	16—20
Life time	год	0,17	0,17
Duration of auxiliary operations	мин./м	0,7	0,5

The average annual productivity of the rock drill is determined by the formula:

$$П_г = \frac{T_{см} \cdot \eta}{\frac{60}{-} + t_{всп}} \cdot N_р \cdot m_{см} \cdot \kappa_э,$$

where: Tcm - duration of a work shift, min. (T = 432 min.);

ŋ - coefficient of effective use of a perforator, taking into account the time spent on preparing a shift and regulated work breaks (ŋ = 0.85);

Vmech - average mechanical drilling speed, m / hour;

tvcp - duration of auxiliary machine operations per 1 meter of borehole drilling, min; Np is the number of working days per year spent on drilling, days; t is the number of drilling shifts per day, see;

ke is the coefficient of extensive use of the perforator, dol. units.

The number of drilling working days per year is determined based on:

- the length of the calendar year (365 days);
- intermittent operation - a five-day working week with two days off;
- duration of scheduled preventive maintenance (1 day);
- the duration of the runs in accordance with the mining development plan (1 day);

- the number of additional working days per year with a 36-hour working week (6 days);

- frequency of major repairs (not performed).

Thus, the number of drilling days per year will be: 257 days.

Average annual productivity of the rock drill:

CONCLUSION

The dissertation, which is a completed scientific and qualification work, contains the solution of problems to expand the field of use of domestic pneumatic perforators with improved parameters, substantiate new layouts and designs of drill heads, determine the rational parameters of percussion systems using the proposed mathematical models and techniques, which is essential for improving the theory of drilling machines and to improve the efficiency of mining enterprises.

The main scientific and practical conclusions drawn from the research performed are as follows.

1. A method for calculating a double striker has been developed, which makes it possible to describe the conditions for the occurrence of bounce (quasi-plastic impact), which increases the impact efficiency by at least 15%.

2. It has been experimentally proven that:

- impact by the piston-striker in the case when the firing pin is located between the rod and the piston, gives a family of "L-shaped" impulses, the total energy of which exceeds the energy of the bell-shaped impulse from the impact of a conventional piston of equal mass;

- impact with a solid piston gives a classic so-called "bell-shaped" impulse, and the speed of the piston at the moment of impact can change

- in the range of 2-14 m / s, and the magnitude of its rebound depends only on the force applied from the side of the solenoid coil;

- the piston-striker starts to move under the action of a force, the nature of which is fundamentally different from the action of a hydraulic (pneumatic) force, however, the effect of bouncing when the piston strikes through the firing pin has always been observed;

- the energy of the family of shock impulses at the impact of a piston with a striker and the amplitude of the first impulses in the family is 10-5-20% higher than these indicators at the impact of a solid piston; the passage of the shock pulse along the length of the rod and the quality of the impacts cause superposition and distortion of the impulses reflected and re-reflected from the ends of the rod; in the shock system, in which the piston-striker is divided into a large (piston) and a smaller (firing pin) part, a total shock pulse of adjustable amplitude and duration is formed, consisting of at least three bursts (sub-pulses), the parameters of which are controlled by changing the distance between the rod and brisk;

- experimentally established the relationship between the clearance of the striker-rod and the following parameters of the impact system: amplitude, number of bursts, total pulse energy, and the bounce effect is most clearly manifested at gaps of less than 5 mm between the striker and the rod.

3. A dynamic model of a submersible striker is developed, expressed by a system of nonlinear differential equations, taking into account: damping coefficient, pressure value, piston cross section.

BIBLIOGRAPHY

1. A.A. № 1398502. Underwater drilling rig / Kipovsky V.Ya. Kochetov S.O., Jungmeister D.A.. -1988.
2. A.A. № 140228. Drilling device. M.Kl. E21C3 / 04, BI No. 7, 1989, authors: A.A. Manin and V.I. Chiriev.
3. A.A. № 713969 Device for the destruction of mountain prod. M. Cl E02
4. F9/22, BI No. 5, 1980, authors: V.G. Kuznetsov, etc.A/c № 857415 МПК E21B4/06. Method of destruction of rocks shock impulses. БИ № 31
5. A.A. № 337505 (СССР). A device for thermal drilling of mineral media under water, authors: Brichkin A.B., Grenbach A.N., Povetkin V.V. 1972.
6. A.A. № №1153052. Impact device for destruction rocks. Moskalev A.N.
7. Stepanyuk A.I., Galyas A.A. Trokhimets N.Ya. M, CL. E 21 C3/00. 1985 г.
8. Aleksandrov E.V. Sokolinsky V.B. Applied theory and calculations shock systems. M. "Science", 1969.
9. Alimov O.D. Investigation of the process of destruction of rocks when drilling holes. Ed. Tomsk University, 1960.
10. Alimov O.D., Dvornikov L.T. Drilling machines. M,Mechanical engineering, 1977, 295 ppr.
11. Asatur K.G. Mechanics of destruction of rocks by high-pressure jets / Uch. allowance. - L: LGI, 1985. 84 ppr.
12. Babakov I.M. Oscillation theory. M., Science, 1965.
13. Babayants G.M., Popov B.A., Nikolaev I.I., Gasparyan S.G. Creation of pneumatic rock drills of a new generation. Mining magazine, 2003, № 2, 52-54 ppr.
14. Drums A.A. and others. The giant in the Khibiny. M : Publishing house "Ore and Metals", 1999. - 288 ppr.
15. Belokobylsky C.B. Shock-self-oscillating movements rock cutting tool. On Sat. Mechanisms and machines shock, periodic and vibration action. Materials of the international symposium 22.11.2000. Oryol, ed. Orel State Technical University, 2000.
16. Blokhin V.S. Drilling tool for percussion machines, M, Nedra, 1974, 200 ppr.
17. Bolotina V.V. Vibrations in technology. Directory. Vol.1, Edited by: Mechanical Engineering. 1978.352.
18. V.A. Britarev and V.F. Zamyshlyaev, Mining Machines and Complexes (Nedra, Moscow), 1984.
19. P.I. Bukreev Drilling wells with jetting pico-drills. - M: Nedra Britarev V.A, Zamyshlyaev V.F. Mining machines and complexes (Moscow: Nedra), 1986.-155 ppr.
20. T. V. Butkevich, Yu. A. Repin Conditions for the effective use of equipment (for example, equipment for the mining industry). Sat. scientific. tr.

"Development and improvement of equipment and technology for mining enterprises." Ed. Institute Gipronikel, L, 1991. 58-62 ppr.

21. V.D.Butkin Design of operating parameters of automated rotary cutter drilling rigs. M., "Nedra». 1979. 208 ppr.

22. Vasiliev V.M. Perforators: A Handbook. – M: Nedra, 1989. 216 ppr.

23. Vetyukov M.M. Yungmeister D.A., Pivnev V.A. Lukashov K.A.

24. Dynamics of a pneumatic hammer with an elastic damper for rotary cutters/scientific-tech. magazine "Mining mechanics", Republic of Belarus, Soligorsk, № 3-4,2002, 45-49 ppr.

25. Vetyukov M.M., D.A. Yungmeister, V.A. Pivnev, K.A. Lukashov.

26. Dynamic Model of a Spring-Loaded DTH Hammer // Pneumatics and Hydraulics, №3, 2002, 50-56 ppr.

27. Vodyanik G.M., Rylev E.V. New rotary drilling machines: Techshka, 1979. — 126 ppr.

28. Vozdvizhensky B.I., Rebrik B.M. Into the depths of the Earth. Exploration drilling - from the past to the future: Nedra. — 168 ppr.

29. Voronovsky K.F. and other Mining, transport and stationary machines, 1985.