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Method and tool for drilling and explosion well expansion in hard rocks

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Abstract:

The paper represents the problem of expanding wells in hard and especially hard rocks. The general direction of solving this problem, the previous methods of solving it and their shortcomings are shown. A new method of drilling and blasting expansion of wells in strong and especially hard rocks is presented, using the energy of a directed explosion of low power to create a three-dimensional network of cracks in the rock mass around the well. The drawings of the tool for drilling and blasting expansion of wells in strong and especially hard rocks at the level of a draft design are given, and the calculation of the explosion energy of a single charge of explosives is carried out, and their mass necessary for such an explosion is determined.

Keywords: expand of wells, hard rocks, drilling, blasting, energy, directed explosion, rock mass, explosives

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1. Introduction

It is known that the drilling of large diameter wells in strong and especially hard rocks is one of the main operations in the extraction of minerals. Despite a lot of research and development of drilling methods and tools, it still remains one of the most difficult, time-consuming and expensive parts of mining. Difficulties in drilling wells are especially noticeable when drilling large diameter wells in hard and very hard rocks, so the following solution to this problem was found. Initially, a small diameter well is drilled, which requires much less time and material costs. After that, this well is expanded to a larger diameter. In total, this takes much less time and money than direct drilling of a large diameter well. This is explained by the fact that when expanding an already drilled well, the destruction of the rock occurs as a result of tangential stresses on the free surface of the drilled well. This requires 5-10 times less energy consumption of the drilling tool than destroying the rock by pressing the tool into a monolithic mass, creating depressions in it in the form of holes (regrinding the rock to the state of sand and dust under the tool), destroying the rock because of normal compressive stresses and thus produce by drilling a well.

2. Methodology

Let's consider some of the main ways of expanding wells and their disadvantages.

There is a known method of expanding wells in rock with a mechanical tool (cutter or drill), which consists in drilling the rock by chipping it on the free surface of a pre-drilled well [1].

Since the zone of rock chipping goes from a larger diameter, where the rock is destroyed by cutters or chisels, to a smaller diameter of the leading cut, there is a need to compress the rock for its chipping on the surface of the pre-drilled well. This requires a little more effort and leads to the need to grind the entire volume of rock of the future well into small particles, which requires quite a lot of energy, time and replacement of expensive drilling tools and quite significant costs for the expansion of the well.

There is a well-known method of expanding wells using thermal devices [2], which consists in the fact that the entire volume of the rock of the future well is drilled thermally, that is, the upper layer of the rock is heated very quickly, which leads to its rapid expansion and separation from the unheated rock from effects of thermal stresses, after which particles of the separated rock are carried away by flows of the heat carrier (gas).

The disadvantage of this method is the significant expenditure of thermal energy from the combustion of fuel, which is used for the destruction and removal of rock by only 5÷10% (percentages), in addition, not all types of rock can be drilled by the thermal method due to the fact that with significant heating some of them start to melt, rock chipping stops and it is very difficult to remove their melt from the well.

There is a well-known method of thermomechanical expansion of wells [3], which consists in the fact that the rock is pre-heated to create stresses in it and then drilled with a mechanical tool, which reduces the effort to destroy the rock and the wear of the mechanical tool [4].

The disadvantage of this method is the significant cost of thermal energy for preliminary heating of the rock, which is used for heating, stress creation and destruction of various types of rocks by only 10-20% (percentages), which in total exceeds the energy costs and the total cost of expanding wells in comparison with mechanical method of expanding wells.

There is a known method of thermocyclic destruction of rocks, which consists in preliminary cooling of rocks [5] adjacent to the drilled well and formation of cracks in them as a result of compression of these rocks and lowering of their temperature, after which drilling of such fractured rock requires significantly less time and material costs. However, the implementation of this method of expanding wells requires rapid cooling of rocks to significant negative temperatures, which can only be done with the help of low-boiling liquids, for example, liquid nitrogen. Currently, the production of liquid nitrogen requires significant energy and material costs, which significantly increases the total cost of expanding the well.

The general disadvantages of thermomechanical expansion methods are a small volume of heated or cooled rocks due to their low thermal conductivity, which leads to significant costs of thermal energy or low-boiling coolant and low overall efficiency. drilling works when expanding wells.

Expansion of wells is also carried out by blasting [6], when several holes are drilled around the drilled well, which are charged with explosives and detonated. The destruction of the rock is mostly in the direction of the drilled well, which creates an expanded well with extremely uneven edges, which in the future is mainly used for the subsequent charging of explosives and explosions for the collapse of the rock mass during mineral extraction. This method [7,8] expansion of wells has a number of significant disadvantages. Thus, the drilling of several holes around the circumference of the well with a conventional mechanical tool requires significant material costs and time, as well as their subsequent charging and extraction of the destroyed rock from the expanded well. A particular difficulty is the extraction of destroyed rock from horizontal or dead-end vertical wells directed downwards. Therefore, this method of expanding wells is mainly used for expansion of emerging wells during mineral extraction.

It should be noted that one of the main disadvantages of the existing rock destruction by explosion is the mismatch of the direction of movement of the detonation and the accompanying shock wave with the direction of rock destruction. Thus, in the known methods of destruction of rocks by explosion [4] the detonation wave travels along the explosive charge in the direction of the central axis of symmetry along the well from the mouth to the surface of the bottom hole in the dead end of the well, while rock destruction occurs mainly in the radial direction to the axis of the well. This means that the primary destruction of the rock is not caused by the directed impact of the shock wave on the walls of the well, but by its reflected impact from the bottom hole or between explosive charges, as well as the effect of high pressure of gasified explosion products on the walls of the well. Such pressure acts in the radial direction, uniformly on all points of the surface of the well and, taking into account its correct cylindrical shape, creates a uniform (radius) field of normal compressive stress in the rock on the surface of the well, i.e. conditions of the most energy-intensive destruction of hard rocks. As a result, a significant part of the energy of the explosion is used to destroy the rock at the wall of the well to the level of sand and dust, and only after the field stress in the rock reaches the free surface at the mouth of the well, tangential stresses arise in the rock, which leads to significant destruction of the rock on the free the surface [9]. After the plug is removed and the well is depressurized, gasified explosion products under high pressure leave the well, which also reduces the efficiency. explosion, which in known methods of explosive destruction of rocks is no more than 20%. that leads to significant destruction of the rock on the free surface. After the plug is removed and the well is depressurized, gasified explosion products under high pressure leave the well, which also reduces the efficiency. explosion, which in known methods of explosive destruction of rocks is no more than 20%. that leads to significant destruction of the rock on the free surface. After the plug is removed and the well is depressurized, gasified explosion products under high pressure leave the well, which also reduces the efficiency. explosion, which in known methods of explosive destruction of rocks is no more than 20% [10].

3. Main material

As can be seen from the listed methods of expanding wells, the most common task is the initial loosening of rocks by creating a leading cavity (drilling a well of a small diameter) and the subsequent destruction of the rock in this leading cavity (mechanical method or further loosening of rocks around the drilled well using a drilled well (thermomechanical methods) However, the methods listed above for loosening the mass of rocks adjacent to the drilled leading well are sufficiently energy-intensive that in the conditions of the growing price of energy carriers, the cost of expanding wells in strong and especially strong rocks and the cost of mineral extraction significantly increases.

Due to the above-mentioned disadvantages of known methods of explosive destruction of rocks, ways to increase efficiency become obvious. explosive substance when destroying strong rocks.

1. The detonation and accompanying shock wave must be directed into the rock, i.e. in the radial direction and directly passes from the explosive to the rock without an air gap.

This will allow the energy of the detonation and the accompanying shock wave to be used for the preliminary destruction of rocks by creating cracks.

2. Explosive charges in the well must be separated and detonated independently of each other, successively from the wellhead to its dead end with a short delay in time.

   The directed explosion of the first discrete charge at the wellhead will create a stress field in the rock in the form of a torus, which, being near the free surface of the bottom hole, will create tangential stresses in the direction of the free surface of the bottom hole at the wellhead, which will lead to the destruction of the rock by creating a system of cracks in it. After that, the next explosive charge is detonated, which also creates a system of cracks on the free surface formed by the cracks of the first explosive charge. All subsequent explosive charges explode sequentially with the same time delay. This allows you to create a system of deep cracks in the rock without spending energy on its grinding.

3. The exit from the well should be closed as long as possible both after the first and subsequent explosive explosions. In this case, the gasified products of the explosion, which are under high pressure, will rush into the cracks in the rock created by the shock wave and will significantly increase both their depth and the cross-section of these cracks. In this case, the energy of the explosive explosion is used to the maximum.

   Based on this, the following method of drilling and blasting expansion of wells is proposed.

The problem of softening the rocks around the well can be solved quite effectively using an explosion in the radial direction (to the axis of the well) when the detonation wave in the charge of the explosive substance (ES) and the subsequent shock wave of the gasified products of the explosion pass directly into the rock of the well wall perpendicular to its surface and not in parallel, as it usually happens when an explosive charge explodes in a well.

Such directionality of the explosion makes it much more effective and requires much less explosives. An even greater efficiency of using this method of directional explosion can be achieved if the explosive charges are separated, placed sequentially in the well, and their successive short-delayed detonation from the mouth of the well to its bottom. Explosive charges in the well must be separated and detonated independently of each other, successively from the wellhead to its dead end with a short delay in time.

The directed explosion of the first discrete charge at the wellhead will create a stress field in the rock in the form of a torus, which, being near the free surface of the bottom hole, will create tangential stresses in the direction of the free surface of the bottom hole at the wellhead, which will lead to the destruction of the rock by creating a system of cracks in it. After that, the next explosive charge is detonated, which also creates a system of cracks on the free surface formed by the cracks of the first explosive charge. All subsequent explosive charges explode sequentially with the same time delay. This allows you to create a system of deep cracks in the rock without spending energy on its grinding, as it happens as a result of an explosion in known ways.

The exit from the well should be closed as long as possible after explosive explosions. In this case, the gasified products of the explosion, which are under high pressure, will rush into the cracks in the rock created by the shock wave and will significantly increase both their depth and the cross-section of these cracks. In the above-mentioned method, the energy of the explosion of explosives is used to the maximum and it goes only to the preliminary destruction of rocks by creating cracks in them, which requires significantly less explosives and allows creating a new method of drilling and blasting expansion of wells and a new drilling and blasting tool (Fig. 1÷5).

The following symbols are used in Fig. 1÷6:
1 – rocks; 2 – well; 3 – metal sleeve; 4 – rod; 5 – guide sleeve; 6 – disk spring; 7 – nut; 8 – emphasis; 9 – explosive charge; 10 – detonation cord; 11 – elastic sheath; 12 – electric wire; 13 – clay and crushed stone plug; 14 – two-way drilling auger; 15 – auger body; 16 – cutters of the auger body; 17 – conveyor screw.

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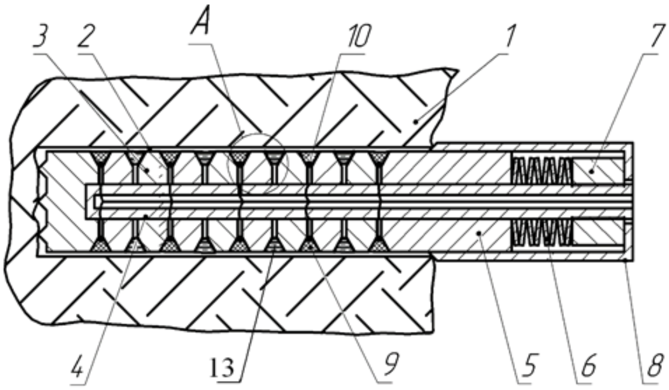

Fig. 1. Longitudinal section of a part of the device for drilling and blasting expansion of wells in the initial position

In Fig. 1 shows a longitudinal section of a part of the device for drilling and blasting expansion of wells in the initial position, the well being expanded and rocks.

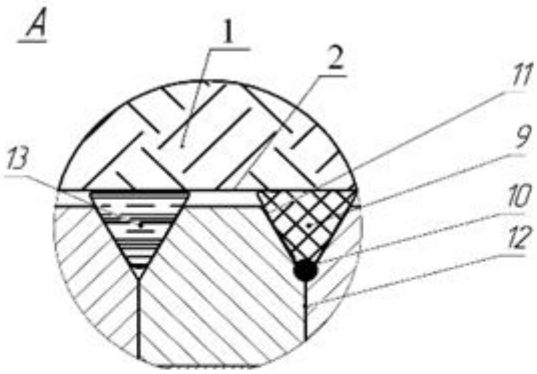

Fig. 2. Longitudinal section of an enlarged fragment of the explosive well expansion device in the initial position in the well

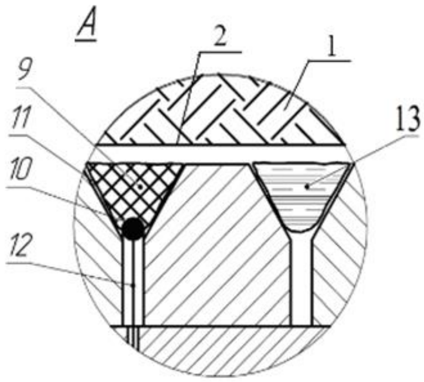

Fig. 3. Longitudinal section of an enlarged fragment of a blasting device for expanding wells in the working position

In Fig. 2 shows a longitudinal section of an enlarged fragment of the explosive well expansion device in the initial position in the well.

In Fig. 3 shows a longitudinal section of an enlarged fragment of a blasting device for expanding wells in the working position.

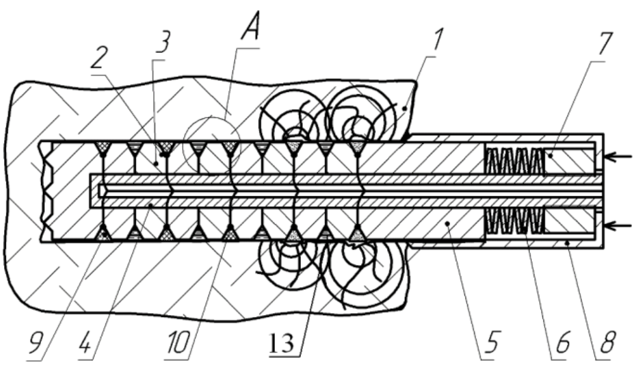

Fig. 4. Longitudinal section of the drilling and blasting device for expanding wells in the working position immediately after the detonation

In Fig. 4 shows a longitudinal section of the drilling and blasting device for expanding wells in the working position immediately after the detonation of two explosive charges and the expanded well in rock.

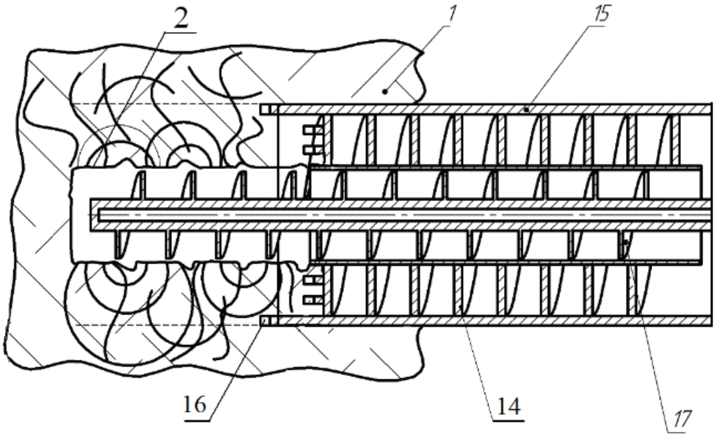

Fig. 5. Longitudinal section of the device for expanding the well after explosive explosions with a mechanical drilling tool

In Fig. 5 shows a longitudinal section of the device for expanding the well after explosive explosions with a mechanical drilling tool, for example, a two-way auger with cutters.

The method of blast expansion of wells is as follows. In a pre-drilled well, individual explosive charges 9 of small power are placed in a hermetic elastic shell 11 in the form of a toroidal cone with an electrodetonator and a detonating cord 10 at the top of the cone, separated from each other by metal bushings (Fig. 3). 1. Clay-crushed plugs 13 in a hermetic elastic shell 11 in the form of a toroidal cone are also located between the explosive charges, which are also located between the metal bushings 3, Fig. 2, 3. Next, the metal bushings 3 move along the axis of the well until they come into contact with each other, displacing part of the charges explosive substance 9 and clay-crushed plugs 13 to the contact with the walls of the well Fig. 2, 3. The well at the mouth is closed from the outside with a stopper 8, which, together with the metal bushings 3 and the guide bushing 5, is pressed with great force to the bottom with the help of hydraulic cylinders, and after that they perform a short-delayed detonation of explosive charges 9 with electric impulses that are fed through the electric wire 12 Fig. 4. The detonation of explosive charges 9 is carried out from the top of the cone of the toroidal shape of the charges, which allows you to direct the detonation and shock wave directly to the wall of the well into the rock without affecting the metal bushings between the charges. After detonation of the explosive charges 9, metal bushings 3 under the action of the pressure of the gases of the explosion products move in the direction of the mouth of the well, compressing the disk spring 6 that protects the instrument from destruction. After a drop in the pressure of the gases produced by the explosion, the metal bushings 3 are returned to their initial position by a plate spring 6, and a network of cracks appears in the rock around the well. Next, the external stop 8 is removed and the rod 4 with metal bushings 3 is removed from the well, and the volume of fractured rock is drilled and extracted from the expanding well with a mechanical drilling tool Fig. 5.

The device for explosive expansion of wells in rock works as follows. A well of a given diameter and length is mechanically drilled in rocks. A rod 4 is inserted into it, on which metal bushings 3 and a guide bushing 5 with equal gaps between them are installed, which are filled with explosive charges 9 in an elastic shell 11 with a detonation cord 10 and an electric detonator in it. Electrodetonators are pre-connected with an electric wire 12 for supplying electric current. Clay and crushed stone plugs 13 are placed between explosive charges 9 in conical toroidal elastic shells 11, between metal bushings 3. Disc springs 6, nut 7, Fig. 1, 2. After that, the nut 7 compresses the plate springs 6 and moves the guide sleeve 5 and the metal plugs 3 in the direction of the wellbore until all the metal sleeves 3 and the guide sleeve 5 are compressed against each other. After that, the stop 8 is installed on the guide sleeve 5 (Fig. 1, 4).

As a result of this movement of the metal plugs 3, the explosive charges 9 in the elastic casings 11 are partially pushed into the gap between the metal plugs 3 and the wall of the well 2 and create direct contact of the charges 9 with the walls of the well in the form of cylindrical rings, and the clay-crushed plugs 13 are partially pushed into the gap between metal bushings 3 and the wall of the well 2 and create clay and crushed stone plugs 13 between explosive charges 9 Fig. 3, 4. After that, stop 8 closes the gap between the guide sleeve 5 and the wall of the well 2. The explosive charge 9 is detonated first, closest to the wellhead. Next, successively, with some delay in time, all other charges of explosives are detonated in 9 Fig. 4. During the explosion of explosive charges 9 between the metal bushings 3, gasified explosive products create high pressure, but due to the fact that the metal bushings 3 can move along the rod 4, they are not destroyed and deformed, but move to the exit from the well, compressing the disk springs 6, and after reducing the pressure of the gasified products of the explosion, the metal bushings 3 return to their initial position. The explosions of explosive charges 9 create a three-dimensional network of cracks in the rock around the well 2, after which the drilling tool in the form of a double-entry drilling auger 14 starts drilling the fractured volume of the rock around the well 2 Fig. 5. Drilling begins with the immersion of 1 cutters of the auger body 16 into the rock, rotating with the body of the auger 15, which create a leading cut and separate part of the fractured rock volume around the well. Further, the cutters located on the spirals of the two-way drilling auger 14 destroy the fractured rock and it is transported by the two-way drilling auger 14 and the transport auger 17 outside the extended well.

After leveling the walls of the well, its expansion may continue with a similar device of a larger diameter. A set of blasting expanders of different diameters allows you to expand the well to the size of ventilation ducts or small workings in a horizontal, vertical or any other direction quite quickly and at low cost.

The main condition of the device's operation is the preservation of its structure after a series of explosions. Therefore, the total work of the impact of a single explosion on the details of the device should not lead to its destruction. That the work of the device parts must be in the area of elastic deformations and it can be calculated using Hooke's law. The most stressed part is the disk spring 6. The scheme of forces applied to the device and the deformation of a separate part are presented in Fig. 6.

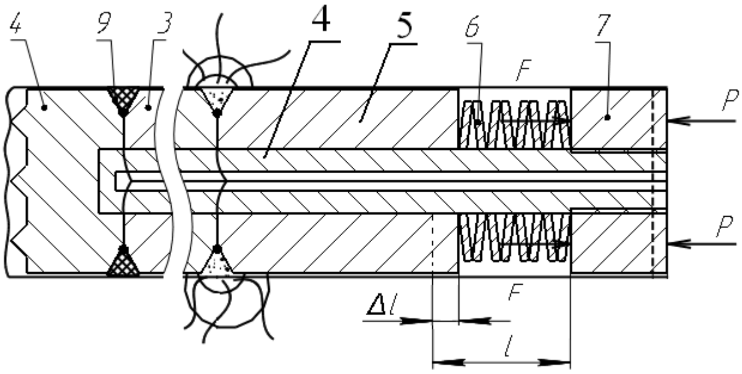

Fig. 6. Scheme of forces applied to the device and the deformation of a separate part

As is known from the course of physics, the elastic force arising from the linear deformation of an elastic element in this case of a spring is equal to:

$$F = k\Delta l \tag{1}$$

where:

F – the force compressing the spring, N,

k – coefficient of elasticity, N/m,

Δl – amount of spring deformation, m.

It is known that for each spring there is a limit deformation value Δlp, exceeding which will lead to the destruction of the spring. The elementary work of the elastic force is determined by the formula:

$$dA = F \cdot d(\Delta l) \tag{2}$$

Substituting (1) into (2), we get:

$$dA = k \cdot \Delta l \cdot d(\Delta l) \tag{3}$$

We determine the total work by the maximum allowable compression of the spring by integrating both parts of equation (3) $\int_0^A dA = \int_0^{l_n} k \cdot \Delta l \cdot d(\Delta l)$. we will get:

$$A_s = \frac{1}{2} \cdot k \cdot \Delta l_n^2 \tag{4}$$

where:

A_s – total work on the maximum allowable compression of the spring,

Δl_n – the maximum permissible deformation of the spring.

Thus, the work of the explosion of a unit charge should not exceed the total work of the maximum allowable compression of the spring.

$A_{\text{des}} \leq A_s$

Work on the destruction of the device is carried out as a result of the expansion of gaseous products of the explosion. However, not all the energy of the explosion passes into the pressure of the gasified products of the explosion. Part of the energy of the explosion goes into the rock together with the shock wave caused by the detonation of explosives and the movement of the products of the explosion in the direction of the detonation wave, so the total ideal work of the explosion A_{charge} should be 1.4÷1.6 times more work of expansion of gaseous products of the explosion, i.e. and A_{des}.

$$A_{charge} = A_{\text{des}} . \times (1.4 \div 1.6) \tag{5}$$

The ideal work of the $A_{id.es.ud}$ explosion is given in the reference literature in kilojoules per kilogram of explosive substance [6]. Divided A charge into $A_{id.es.ud}$ for the selected explosive, we get the mass of a unit explosive charge in the form of a truncated torus, which can be detonated without destroying the device.

$$m_{vc.charge} = \frac{\mathrm{A}_{charge}}{\mathrm{A}_{\text{ud.ES}}} = \frac{[J]}{[J]/[kg]} = [kg] \tag{6}$$

Next, based on the density of the selected explosive, we determine the volume and dimensions of the toroidal cone of the charge.

The distance between the charges should be as minimal as possible, taking into account the clay plug.

The proposed method and device for drilling and blasting expansion of wells make it possible to significantly increase the speed of expansion of wells hard or especially hard rocks, as well as reduce the cost of drilling works account of the following factors.

The use of a directional explosion and its detonation and shock wave, which directly passes into the rock in the radial direction.

The use of separate charges of explosives to create a toroidal spherical field is tense near the free surface that is formed, which leads to successive stepwise destruction of the rock by the action of tangential tension on the free surface of the rock exposed by each explosion in the cracks that appear.

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The use of a time delay in the detonation of charges for the formation of cracks and the operation of each subsequent charge on the "free" surface.

Limitation of charges with plugs and sealing of the well with an external plug for the formation of a directional explosion and greater work during the expansion of gasified products of the explosion, which are under high pressure, the efficiency of use of which in this case reaches up to 80%.

Drilling of rock destroyed by an explosion, which is reduced in its main mass (inside the leading cut) to loosening of fractured rock, which is tens of times cheaper than drilling of the same volume of solid monolithic rocks.

4. Conclusions

It should be noted that the main difficulty when drilling or expanding wells in strong or particularly strong rocks with a mechanical tool is the destruction of monolithic volumes of these rocks by the action of normal compressive stresses created by the tool, the values of which are the greatest for the destruction of strong or particularly strong rocks. In the case when there is a free surface in the zone of action of a mechanical tool (cutter or drill bit), (in front or from the side) the destruction of strong or particularly strong rocks occurs under the action of tangential stress (and in the case of fractured rock, they act in a thin layer) which for the destruction of strong rocks, it is many times less than the normal compressive stresses in the monolithic volume of the rock. In this method of drilling and explosive expansion of wells, well expansion drilling is performed on fractured rocks destroyed by an explosion, which is 5÷10 times faster and more economical (in terms of tool wear and energy consumption) compared to known methods of expanding wells with a mechanical tool.

Offered the method and device of drilling and blasting expansion of wells is much more effective and cheaper than all known methods of expanding wells in hard and especially hard rocks. Its efficiency increases even more in the case of repeated expansion of the well using this method and device, when the massif of rocks is already a network of holes that will be significantly increased by repeated exposure to a directed explosion, therefore offered the method and device for drilling and blasting expansion of wells is expedient to use repeatedly for expanding wells to the size of ventilation channels and small diameter workings.

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