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TECHNOLOGIES INSTALLATION FOR CUTTING STONE WITH ABRASIVE AND DIAMOND TOOL

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Abstract

On the basis of undertaken studies and calculations, taking into account a wide range of materials with varying strength and abrasiveness, the new device for cutting artificial and natural stone materials was developed. This device appeared to set the feed rate for cutting material, the circuitous speed of the working body and also regulate the supplying of water in the cutting area. Products arriving at the construction site must have the maximum degree of factory readiness. However, it is impossible to do without pre-processing at the site, since, for example, facing plates are supplied in rough form, and the features of each building (slots of facades, internal walls and partitions, dimensions of rooms) require cutting a significant part of the plates. It is known that the working speed of an abrasive reinforced wheel is 80 m/s, and a diamond disc when cutting hard materials is 40 m/s. Changing the peripheral speed is carried out by changing the pulleys of the V-belt transmission. Water is supplied to the contact zone using nozzles fixed in the casing of the working tool. On the installation panel, there are buttons for controlling the hydraulic system, which provides clamping of the cut product, movement of the cutting disk in the vertical direction and feeding of the work table to the cutting zone, with adjustable speed. The closed water circulation system works as follows: water is sucked through the filter into the pump, which feeds it through the regulator to the nozzles. Then, through the drainage lines, the water enters the reservoir and sedimentation tank, after which it drains into the tank through the filter.

Key words:
abrasive, thermal conductivity, strength, lateral surface, binding.

Introduction

Cutting refractories and natural stone is a massive operation, during which a wide range of materials with different physical and mechanical properties must be processed.

In the process of performing heat-installation works, processing of refractory products is carried out in two ways: a) on the assembly site, outside the workplace, where the details of the required profile are prepared (Kresan *et al.* 2021). Mass constructive cutting of halves, quarters and other missing firebricks is performed here; b) directly at the workplace in order to fit them in accordance with the thickness of the seams, which are regulated by technical conditions and determined by tolerances on the sizes of refractory products. Products arriving at the construction site must have the maximum degree of factory readiness (Rogovskii *et al.* 2020). However, it is impossible to do without pre-processing at the site, since, for example, facing plates are supplied in rough form, and the features of each building (slots of facades, internal walls and partitions, dimensions of rooms) require cutting a significant part of the plates (Kresan *et al.* 2022). In addition, on construction sites, it is necessary to correct defects in delivered products related to non-observance of geometric dimensions, cracked stone, chips, breaks, etc.

Products made of concrete and reinforced concrete are also subject to cutting (Rogovskii 2020). The specifics of performing these works determine the choice of equipment and working tools for performing cutting operations (Palamarchuk *et al.* 2021).

Formulation of problem

In the process of research, which was jointly carried out by the Institute of Mechanical Engineering and KNUCA (Nazarenko *et al.* 2020), it was established that it is economically feasible to cut highly abrasive refractories (dynas, fireclay) and natural stone (tuff, marble limestone) with a strength of up to 60 MPa with abrasive reinforced circles, and stronger materials, such as high-alumina, acid-resistant, kaolin refractory, granite, sandstone - with diamond discs (Nazarenko *et al.* 2021a).

Taking into account such a variety in the strength of materials, the Kyiv National University of Civil Engineering and Architecture has developed a device for cutting refractories and natural stone, the working tools of which are abrasive reinforced circles and diamond discs (Nazarenko *et al.* 2021b).

Purpose of research

During the development of the installation, the following tasks were solved:

The working mechanism of the abrasive wheel was studied depending on the conditions of its use.

Power parameters during cutting are determined.

A mechanism for maintaining the depth of cut in the process of self-sharpening and wear of the working element when using abrasive reinforced discs has been developed.

Research results and discussion

There are two types of cutting with diamond and abrasive discs – dry and wet. Damp is used primarily to limit the amount of dust. At the same time, it allows you to work with the material more deeply. It is used, in particular, for cutting concrete. Both dry and wet cutting tools can be used for stone processing. It is important to note that some diamond cutting wheels are designed exclusively for use with water, while dry cutting tools can be used with or without water, depending on the tool and the material being cut.

Among the variety of distinctive features when using an abrasive tool for such operations, its self-sharpening property occupies a special place. Self-sharpening, as a constant property of an abrasive tool, is characterized by the following provisions: 1 - two processes occur on the cutting edges of an abrasive tool - abrasion or microdestruction of the cutting edges, which means their blunting, and the process of macrodestruction of the edges, that is, the restoration of their sharpened form. The action of these two processes determines the cutting ability of the tool; 2 – limited self-sharpening corresponds to local destruction of grains, ending with dulling of grains, volumetric destruction of grains and their separation – unlimited self-sharpening until complete wear of the tool.

Abrasive tool wear is a rather complex phenomenon that depends on many factors: the properties of the abrasive material and its grain size, the geometric parameters of the circle, the type and mode parameters of the material processing process, the properties of the bond and its hardness.

The analysis of the causes of wear, which includes the specifics of the physical and mechanical processes that occur in the contact zone of the abrasive grain with the processed material, makes it possible to establish the presence of several separate modes of wear, to identify their characteristic areas of distribution, as well as possible schemes of transition from one mode to another.

In the process of researching the mechanism of the abrasive wheel, depending on the conditions of its use, it was established that when it is used without cooling, tool wear occurs mainly due to the thermomechanical destruction of the polymer matrix, since the wheel can perform cutting of materials of different strengths. When cutting with water cooling, the matrix temperature decreases, fundamentally changing the wheel wear mechanism. During cutting, blunted abrasive elements from its matrix as a result of their shock interaction with the material being processed prevail (Abrashkevich *et al.* 1988).

The self-sharpening of the wheel is obtained in the case when blunt abrasive grains break out of the polymer matrix, as the condition is fulfilled:

$$\sigma = \frac{P_y}{b^2} + \frac{G\,P_z\,(3x-h)}{3\,b^2+0.6\,h^3} > \sigma^{kp}, \qquad (1)$$

where σ – the maximum stress that occurs at the base of the grain, MPa;

P_y, P_z – normal and tangential component of cutting force, N;

x, b – parameters that characterize the grain, m;

h – grain depth, m;

σ^{kp} – the strength of the bond of the circle.

In the process of work, as the abrasive grains are blunted, wear surfaces appear, which lead to an increase in the forces acting on the wheel and the power used to destroy the processed material (Fig. 1).

At the same time, the wheel is self-sharpening if the forces are sufficient to break the abrasive grains from the polymer matrix. Otherwise, the cutting stops, and as a result of the active feeding forces, the tool is deformed, and as a result, the abrasive reinforced circle is destroyed.

Determination of power parameters when cutting with abrasive reinforced wheels was performed experimentally, due to a large number of unstable cutting parameters (size of abrasive grains, distance between them, mechanical properties of the connection, properties of materials).

Figure 2 shows the diagram of forces acting on an abrasive reinforced wheel during cutting.

To determine the power of the drive, the tangential forces that perform the work of destruction and overcoming friction between the side surfaces of the wheel and the material were determined:

$$P_z = P_{z0} + P_{z\rightleftarrows cut}, \quad (2)$$

where P_{z0} – the tangential effort spent on the work of the side surfaces of the circle, H;

$P_{z\rightleftarrows cut}$ – tangential force spent on the end destruction of the rock, N.

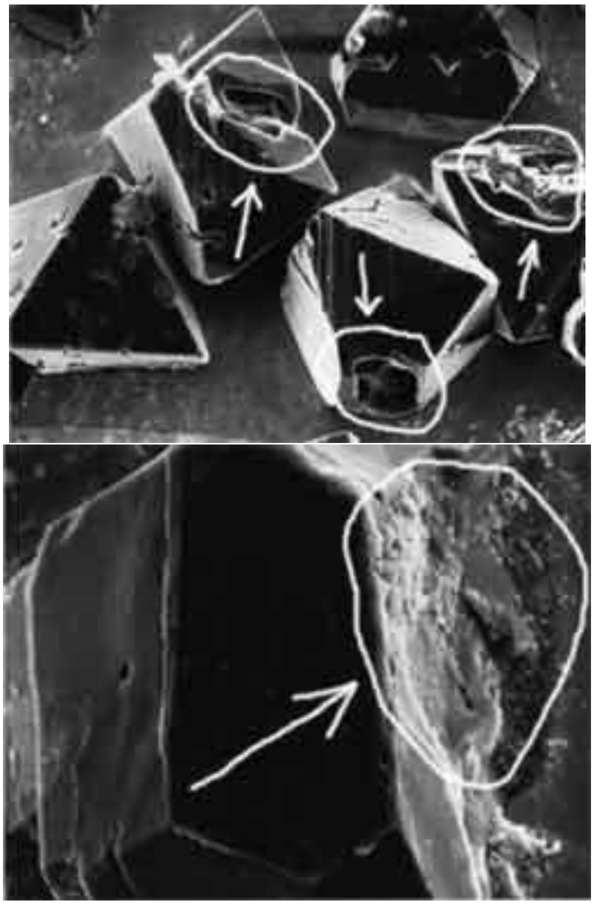


Figure 1. Micrographs of abrasive grain wear sites.

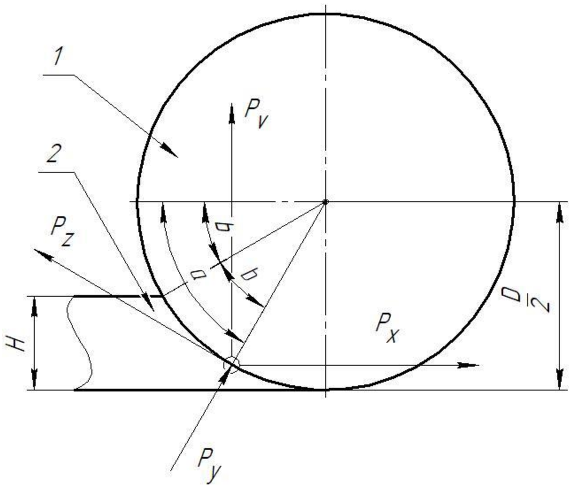


Figure 2. Scheme of forces acting on an abrasive wheel: 1 – abrasive reinforced wheel, 2 – rock, P_b – vertical component of cutting force, H; P_y – the normal component of the cutting force, H; P_z – tangential component of cutting force, H; P_x – horizontal component of cutting force (feed force), H; α – angle, which determines the point of application of the resulting cutting force, degrees; H – cutting depth, m; D – diameter of the circle, m.

$$P_{z\rightleftarrows cut} = K_z \frac{V_n^x}{V_p^y} \sigma_в H^{z_1}, \quad (3)$$

where K_z – coefficient depending on the composition of the abrasive mass of the wheel;

x, y, z_1 – degree indicators;

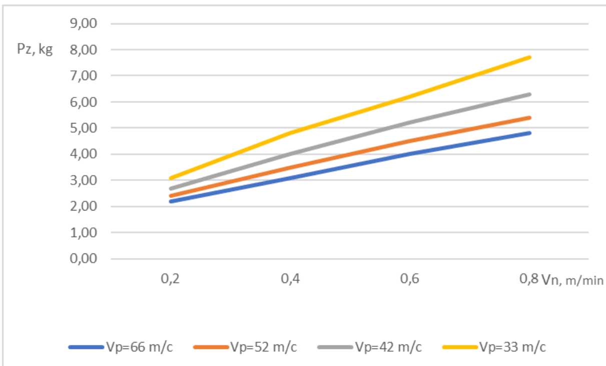
$\sigma_в$ – temporary resistance to uniaxial rock compression, N/m^2;

H – cutting depth, m;

V_n – feed speed, m/s;

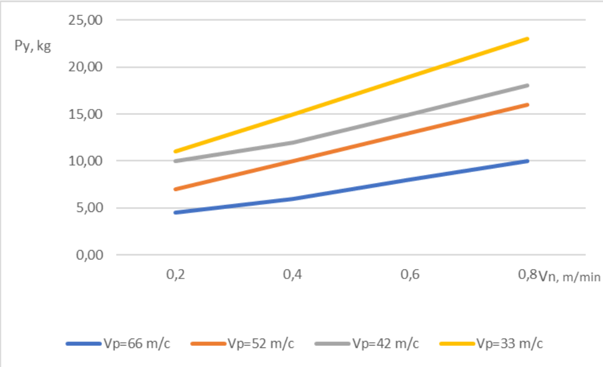
V_p – circular cutting speed, m/s

Figures 3; 4; 5; 6; – show the dependence of normal and tangential forces on working speeds and feed rates during cutting.



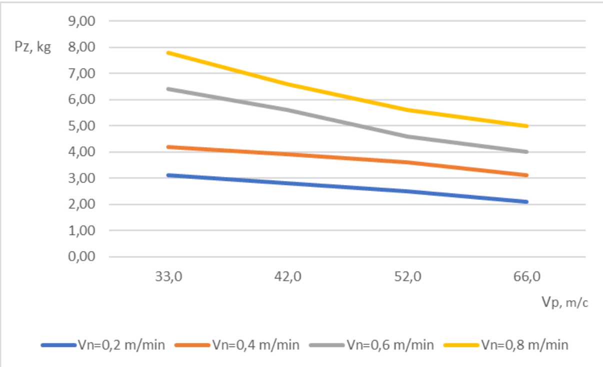
Vn	Vp=66 m/c	Vp=52 m/c	Vp=42 m/c	Vp=33 m/c
0,2	2,20	2,40	2,70	3,10
0,4	3,10	3,50	4,00	4,80
0,6	4,00	4,50	5,20	6,20
0,8	4,80	5,40	6,30	7,70

Figure 3 Dependence of P_z – tangential cutting component on V_n – feed speed at a constant V_p – circular cutting speed.



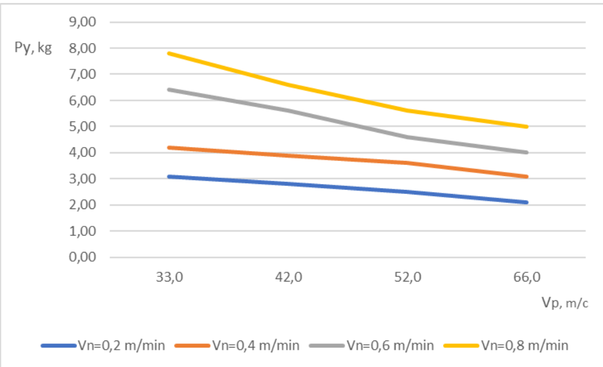
Vn	Vp=66 m/c	Vp=52 m/c	Vp=42 m/c	Vp=33 m/c
0,2	4,50	7,00	10,00	11,00
0,4	6,00	10,00	12,00	15,00
0,6	8,00	13,00	15,00	19,00
0,8	10,00	16,00	18,00	23,00

Figure 4. Dependence of P_y – the normal cutting component on V_n – feed speed at a constant, V_p – circular cutting speed.



Vp	Vn=0,2 m/min	Vn=0,4 m/min	Vn=0,6 m/min	Vn=0,8 m/min
33	3,10	4,20	6,40	7,80
42	2,80	3,90	5,60	6,60
52	2,50	3,60	4,60	5,60
66	2,10	3,10	4,00	5,00

Figure 5. Dependence of P_z – tangential cutting component on V_p – circular cutting speed at a constant V_n – feed speed.



Vp	Vn=0,2 m/min	Vn=0,4 m/min	Vn=0,6 m/min	Vn=0,8 m/min
33	11,50	15,00	19,00	22,00
42	9,00	12,50	15,00	16,50
52	8,00	10,00	12,00	14,00
66	5,00	6,00	8,00	11,00

Figure 6. Dependence of P_y – the normal cutting component on V_p – circular cutting speed at a constant V_n – feed speed.

As a result of experimental data processing, the value was obtained K_z; X; Y; Z_1. Thus, the tangential forces spent on rock destruction can be determined from the dependence:

$$P_{zcut} = 35,5 \cdot 10^{-2} \frac{V_n^{0,75}}{V_p^{y}} \sigma_в H^{0,75} \quad (4)$$

The power spent on cutting can be determined depending on:

$$N = N_{fric} + N_{cut} = N_{fric} + \frac{K_z}{102} V_n^{x} \sigma_в H^{z_1} \quad (5)$$

where N_{fric} – the power spent on the friction of the side surfaces of the circle, kW;

N_{cut} – power used for face cutting, kW.

The main influence on the power of the drive is provided by the feed rate. The influence of the peripheral speed is much smaller, since with the increase of the peripheral speed twice, it increases by only 12-14%. This is explained by the fact that as the peripheral speed increases, other forces being equal, the tangential forces decrease. This can be explained by the fact that when cutting stone, the change in circumferential speed does not have a significant effect on the power spent on cutting.

In this regard, it was assumed that when cutting with abrasive wheels N_{cut}, it does not depend on the wheel speed, and with an increase in the wheel speed, it increases N_{fric}

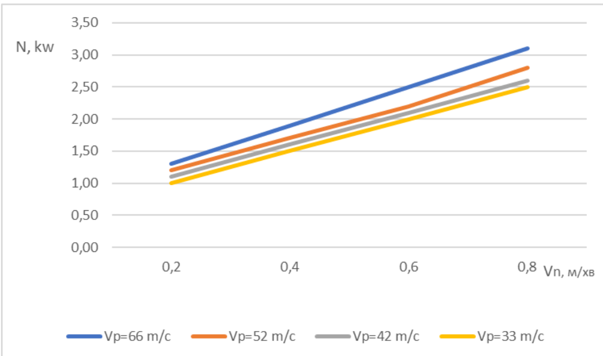
$$N_{fric} = K_n V_p^{x_1} \sigma_в H^{y_1}, \quad (6)$$

where K_n – the coefficient that depends on the design of the circle;

x_1; y_1 – exponents.

As a result of experimental data processing K_n; x_1; y_1. Thus, the power spent on the work of the side surfaces of the circle can be determined from the dependence:

$$N_{fric} = 5,35 \cdot 10^{-5} \cdot V_p^{0,7} \sigma_в H^{0,75}, \quad (7)$$



Vn	Vp=66 m/c	Vp=52 m/c	Vp=42 m/c	Vp=33 m/c
0,2	1,30	1,20	1,10	1,00
0,4	1,90	1,70	1,60	1,50
0,6	2,50	2,20	2,10	2,00
0,8	3,10	2,80	2,60	2,50

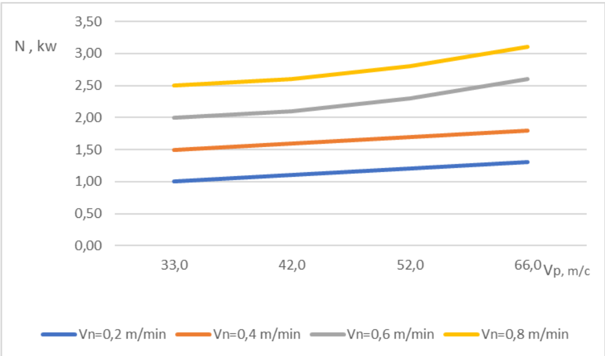
Figure 7. Dependence of N – power spent on cutting on V_p – circular cutting speed at a constant V_n – feed speed.

By substituting formulas (4) and (7) into (2) and (5), we determine the tangential forces and power spent on cutting:

$$P_z = \left(\frac{5{,}4\cdot 10^{-3}}{V_p^{0,3}} + 35.5\cdot 10^{-2}\frac{V_n^{0,75}}{V_p}\right)\sigma_в H^{0,75}; \quad (8)$$

$$N = \left(5{,}35\cdot 10^{-5} V_p^{0,7} + 35\cdot 10^{-4} V_n^{0.75}\right)\sigma_в H^{0,75} \quad (9)$$

Figures 7; 8 – power dependences are given in accordance with the changes occurring in the working environment.



Vp	Vn=0,2 m/min	Vn=0,4 m/min	Vn=0,6 m/min	Vn=0,8 m/min
33	1,00	1,50	2,00	2,50
42	1,10	1,60	2,10	2,60
52	1,20	1,70	2,30	2,80
66	1,30	1,80	2,60	3,10

Figure 8. Dependence of N – power spent on cutting on V_n – feed speed at a constant V_p – circular cutting speed.

The force parameters when cutting with a diamond tool were determined according to the methodology developed by the Institute of Superhard Materials of the National Academy of Sciences of Ukraine.

As a result, it was established that the power of the drive required for cutting refractories and natural stone with a strength of up to 60 MPa is 5...5.5 KW, and for stronger materials with diamond discs, about 7 KW. Based on this, the power of the electric motor of the installation for cutting refractories and natural stone with abrasive reinforced circles and diamond discs was taken as equal to 7.5 KW.

Preservation of the depth of cut in the process of self-sharpening and wear of the working element was achieved due to the developed hydraulic tracking system

The purpose of the follower hydraulic drive is to move the loaded working body according to a given law and at a given speed, while providing the necessary amplification of the output power.

On the side walls of the protective casing 7, which has windows 8, 9, which are made of transparent materials, a photoresistor 10 is located. The photoresistor 10 consists of the left 11 and right 12 bases. On the right 12 base, which has a substrate 13, there is a semiconductor layer 14 with contacts 15 on the edges for supplying voltage. The light-emitting element 16 is located on the left 11 base of the photoresistor 10. Contacts 15 of the photoresistor 10 are connected to the relay 17 of the electromagnetic distributor 18, which is included in the hydraulic circuit.

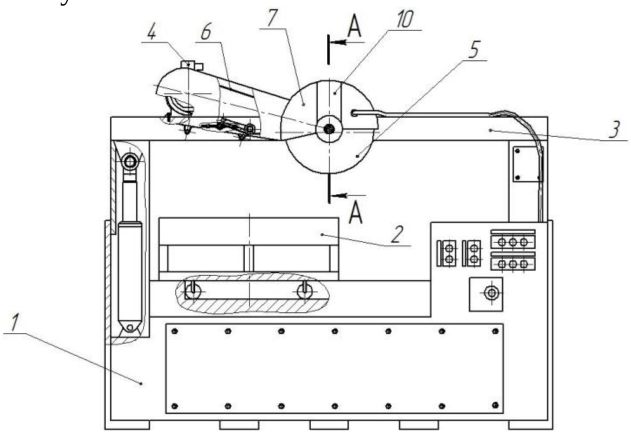


Figure 9. Cutting machine with tracking system: 1 – beds; 2 – work table; 3 – upper part of the frame; 4 – engine; 5 – working body; 6 – belt drive; 7 – protective casing.

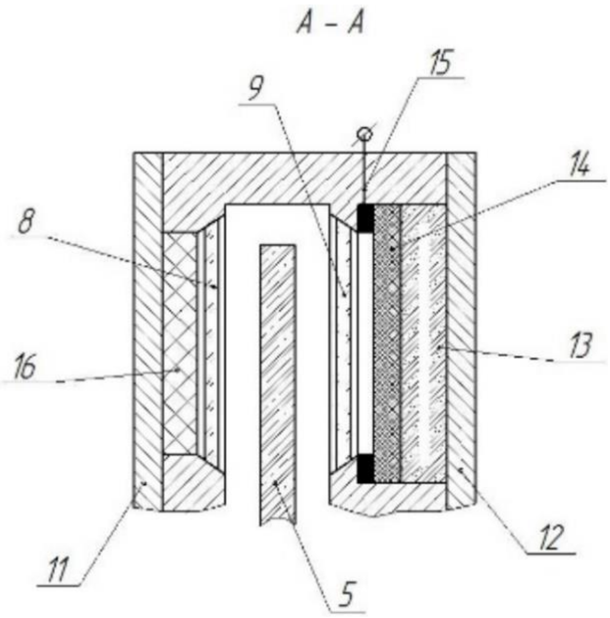


Figure 10. Protective casing with a built-in photoresistor: 8 – window; 9 – window; 10 – photoresistor; 11 – left part of the photoresistor; 12 – the right part of the photoresistor; 13 – substrate photoresistor; 14 – semiconductor layer; 15 – contacts; 16 – light-emitting element; 17 – relay; electromagnetic distributor.

The hydraulic circuit (Fig. 11) has a pressure line 19 and a drain line 20, which fit the hydraulic cylinders 21, 22 for raising and lowering the upper part of the frame 3. To ensure the synchronous operation of the hydraulic cylinders 21, 22, a flow divider is placed on the pressure line 19, where the hydraulic lock 23 is installed 24 and shut-off valves 25, 26. In order to avoid overloading the hydraulic system, safety valves 27, 28 together with shut-off valves 29, 30 are included in the pressure line 19.

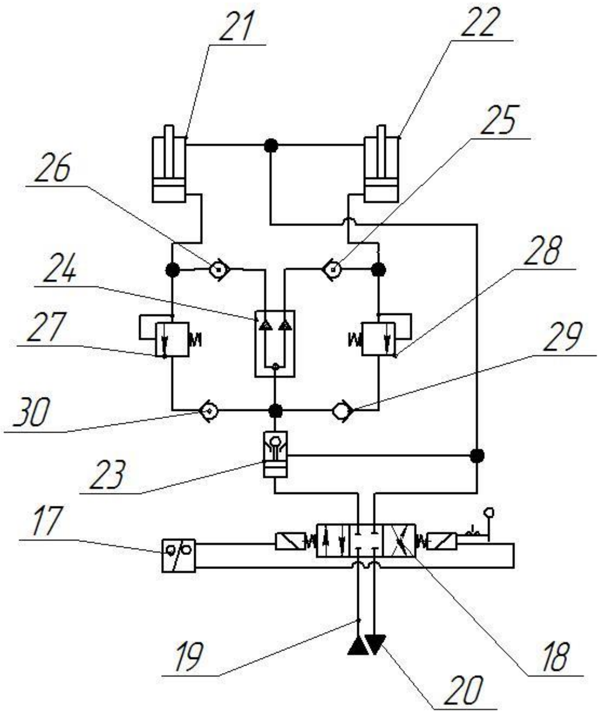


Figure 11. Hydraulic diagram: 19 – pressure main; 20 – drain main; 21 – left hydraulic cylinder; 22 – right hydraulic cylinder; 23 – hydraulic lock; 24 – stream divider; 25 – stop valve; 26 – stop valve; 27 – safety valve; 28 – safety valve; 29 – stop valve; 30 – stop valve.

A cutting machine with a tracking system works as follows.

We turn on the electric motor 4, which, using the V-belt transmission 6, transmits the torque to the working body 5. By switching the positions of the electromagnetic distributor 18, we activate the hydraulic cylinders 21, 22 for raising and lowering the upper part of the frame 3 with the working body 5 of the machine and set the cutting depth. Switch the electromagnetic distributor 18 to the neutral position. Work table 2, on which the workpiece is installed, is fed to the cutting zone. A cutting process is carried out during which the working body 5, for example, an abrasive disc installed on the upper part of the frame 3, is subject to abrasion (Abrashkevich *et al.* 2006). Thus, the light flux emitting the light-emitting element 16 of the photoresistor 10, which passes through the protective windows 8, 9 with the reduction of the working body 5, increases its impact on the semiconductor layer 14. An imbalance of the electrical signal occurs, which through the relay 17 switches the positions of the electromagnetic distributor 18 and activates the hydraulic cylinders 21, 22, which lower the upper part of the frame 3 of the machine together with the working body 5 to the specified cutting depth, after which the distributor 18 returns to the neutral position. In this way, a cutting machine with a tracking system ensures a constant depth of the slot.

Table 1. Technical characteristics of the installation

Parameters	Value
Diameter, mm: diamond cutting wheels abrasive reinforced circles	 500 500
Rotational frequency, rpm: diamond cutting wheels abrasive reinforced circles	 1500 3000
Wheel speed m/s: diamond cutting wheels abrasive reinforced circles	 40 80
The largest cutting depth, mm: diamond cutting wheels abrasive reinforced circles	 150 150
Power of the electric motor, kW	7,5
Capacity of the cooling system, l	50
Overall dimensions, mm	2500×1450×2000
Weight, kg	1820

It is known that the working speed of an abrasive reinforced wheel is 80 m/s, and a diamond disc when cutting hard materials is 40 m/s. Changing the peripheral speed is carried out by changing the pulleys of the V-belt transmission. Water is supplied to the contact zone using nozzles fixed in the casing of the working tool.

On the installation panel, there are buttons for controlling the hydraulic system, which provides clamping of the cut product, movement of the cutting disk in the vertical direction and feeding of the work table to the cutting zone, with adjustable speed.

The closed water circulation system works as follows: water is sucked through the filter into the pump, which feeds it through the regulator to the nozzles. Then, through the drainage lines, the water enters the reservoir and sedimentation tank, after which it drains into the tank through the filter.

It should be noted that when cutting stone with abrasive reinforced wheels, water is needed only for dust removal and its consumption is 5...6 l/min, and when cutting with a diamond disc, which must be cooled, the water consumption increases to 20 l/min.

Conclusions

On the basis of conducted research, calculations, taking into account a wide range of materials with different strength and abrasiveness, a device with a tracking system was developed, which will allow more efficient performing of cutting operations directly both in stationary conditions and when performing such operations on construction sites. The tracking system of the machine ensures constant cutting depth when using abrasive reinforced wheels. Technical characteristics are presented in Table 1. When performing cutting on the developed installation, it became possible to set the feed speed, peripheral speed, which are the main parameters when performing this process, as well as to regulate the water supply to the cutting zone.

Thus, the device will allow to expand the range of cutting materials and increase the operational performance of abrasive and diamond tools.

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