Providing adaptive properties of the drive of a rotary drilling machine

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Abstract. The article is devoted to the issue of automatic adjustment of the drilling machine to operating modes close to optimal. Information about the method of automatic control of the rotational drilling process is provided. The essence of the method consists in a special design of the drive, in which the work of the hydraulic motor and the hydraulic cylinder are connected through the working process. As a result of this connection of hydraulic elements, the torque of rotation on the hydraulic motor controls the feed of the hydraulic cylinder. Tuning throttles provide adjustment of modes to the required range of drilling conditions. Depending on the strength of the rock being drilled and the operating conditions of the drilling machine, the drive automatically changes the feed rate, thus ensuring maximum productivity. Several variations of this adaptive drive of the drilling machine are described. A description of the authors development, the drive scheme, and a description of the principle of operation is given. The advantages of the adaptive drive and its disadvantages are shown.

1 Introduction

There is a wide distribution of drilling machines of various capacities and productivity for various applications and, as a rule, these are rotary type drilling machines.

Various methods and principles of drilling process management are applied with varying degrees of automation and control methods, and these methods have certain advantages and disadvantages. Let's look at the main ones.

Indicators of the drilling process, along with the physical and mechanical properties of the material being drilled, depend on two operating parameters: the feed force (or feed speed) and the rotation frequency of the drill rod. At the same time, the following methods of their regulation are the most characteristic[1,2]:

1. Regulation of the constant value of the specific feed S (mm / revolution). The rotation speed and the feed pressure are regulated.

2. Maintaining a constant value of thrust (in theory of cut - free feed). The speed of rotation is adjustable. For example, [3].

3. Maintaining a stable speed value when adjusting the feed force

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4. ensure maximum drilling performance through microprocessor control of feed force and rotation speed.

5. Maintaining a rational ratio of rotation speed and feed force depending on the strength of the drill rock (adaptive parameter control) [4].

All of the above methods, but to a lesser extent the latter method, are characterized by difficulties in drilling management when factors that require the participation of the operator of the drilling machine-the driller.

It is known that the drilling process is influenced by external and internal factors. External factors include the variability of drilling conditions (changes in the strength of the drilled rock, rock viscosity, drilling depth, the presence of inclusions, layers with different properties). Internal (technological) factors include wear of the cutting tool, strength limitations of the design and drive power, etc.

Therefore, the operator-controlled drilling method is more often used, taking into account the manifestation of influencing factors, sometimes relying on the readings of sensors for the state of the drilling process[5]. For powerful drilling systems, microprocessor control of the drilling process is used, taking into account the influencing factors. But these systems are very expensive and are rarely used for relatively low-power drilling machines.

Obviously, there is a problem of automating the drilling process for relatively low-power drilling machines, relatively inexpensive and reliable methods and structures.

At the same time, automatic control of the drilling process must be carried out taking into account these and other factors. According to the authors, taking into account the well-known publications [5,6, 7,8] and the experience of using a similar adaptive drive [9], the most appropriate from the point of view of simplicity of solving the problem at minimal cost is the use of an adaptive hydraulic drive.

In this question, the concept of drilling process management without involving automation and computer technologies is known [10]. This method is known, it has been developed by a number of researchers and tested in the industry [11].

The adaptive drive of the drilling machine will automatically adjust the drilling parameters to operating modes that are close to rational, when the working conditions of the drilling machine change.

For example, in a well-known adaptive drilling machine, the feed force and rotation speed of the drill rod are regulated within certain limits when drilling conditions change [12]. The article considers the possibility of automating the drilling process by using the drive of a drilling machine with two working movements, which has an adaptive structure. This drive will provide the connection of thrust and rotational speed, so that the thrust force of will control the torque to the drill rod (shaft motor).

The theoretical basis for the essence of the adaptive drilling process is the results of the analysis of the interaction of the cutter with the destroyed material [4]. the main points of this analysis are given below.

2 Elements of the theory of adaptive rock cutting

Under the adaptive interaction of the cutter with the rock, we will consider such cutting process, such a variation of the relationship between feed and cutting when energy is supplied to the cutter, samoraspustitsya between the mutually perpendicular components, which are used in the cutting of coal to determine how the components of cut (Z) and flow (Y). This implies that the cutter is moved in the direction of the Z component, and mechanically restricted from other movements, with the exception of micromovements due to the backlash, bending of the holder, resilient supports and rails. For rice. 1 the working model of such interaction is given. elements of adaptive rock cutting

The model of adaptive interaction of a cutter with a rock conventionally represents one of the types of adaptation of cutting tool parameters to the variability of strength, visco-plastic characteristics of the destroyed material. The essence of automatic change of cutting parameters is to redistribute the load between the cutting force (Z) and the feed (Y). note that the cutting force (Z) is formed mainly by the pressure of rock on the front face of the cutter and reflects the phenomenon of separation of this face of the destroyed elements in front of the front face of the cutter. The feed force (Y) is formed by the resistance to indentation of the cutter blunt area from its back face. The destruction of the rock is caused by compressive loads and is accompanied by small crushing and crushing of rock particles.

Using the above model, we consider the physical essence of the formation of feed components (Y) and cutting (Z) in the adaptive interaction of the cutter with the destroyed material. The process of cutting rock is characterized by the following phenomena:

1. The isolation elements under the action of the cutter on the array, to a greater extent in front of the front face (surface).

2. the Size and shape of the separated elements depend on the compliance of the material characteristics with the characteristics of the cutting part and cutting parameters.

3. the cutting Process is characterized by the dissipation of energy that goes to the deformation of the material, its crumpling and fine grinding. And above all under the back face of the incisor. Minimization of input energy dissipation is the direction to achieve optimal cutting, with a minimum specific energy consumption of the cutting process.

4. The separation element is preceded by the stress state in the array, the magnitude, the direction of this voltage, physico-mechanical properties of fractured material, the geometry of the cutting determine the energy consumption for destruction.
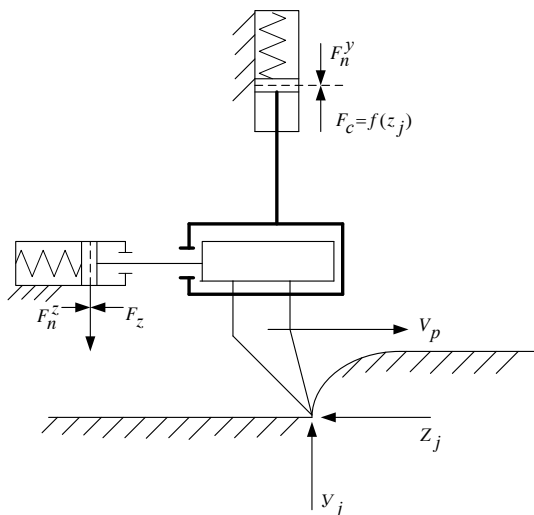

Fig. 1. Diagram of forces acting in adaptive cutting.

Consider the process of forming the load on the cutter in the cutting direction and in the feed direction (Fig. 1). Under the action of forces applied to the cutter, and when it moves in the direction of cutting V p, volumetric stresses are created in the material being destroyed. The shape and intensity of stresses in the material are determined by the inhomogeneity of the material and its various deformability in the main directions studied along The z and Y axes, coinciding with the lines of action of the corresponding components. As you know, the inhomogeneity and fracturing of real coals and rocks have a random orientation and are manifested in the Z and Y directions in different ways.

In the feed direction along the Y-axis, the action of the cutter can be described as the indentation of its blunt site into the half-space, and the resistance to this indentation is determined by the elastic-plastic properties and compression resistance (along the Y-axis) in the undercut zone [13]. The physical processes that characterize the interaction of the cutter and the rock are well studied for power cutting and are the basis for indicators of rock fracture strength [14,15]. The hardness index "contact strength" is widely used to evaluate the properties of rocks. The feed force Y can be represented by the expression:

$$Y = f_1(\, P^y_\kappa \, , \mu^y, E^y, \underline{F}^y_3),\tag{1}$$

where: P^y_κ, μ^y, E^y, F^y_3 – contact strength of the material being destroyed, its elastic modulus, modulus of deformability, and the projection of the cutter blunt site on a plane perpendicular to the y axis, respectively. The "y" index corresponds to the given characteristics in the direction of the y axis.

In power cutting, the resistivity and volume of the deformed material under the blunt pad is largely determined by the size of the pad itself, the contact strength of the material, and does not depend on the front cutting angle, the sharpening angle (if the rear angle is const) and to a small extent depends on the rear angle of the cutter.

In adaptive cutting, this specific volume pressure and deformation under the cutting platform depend on physical phenomena occurring on the front face of the cutter. Indeed, according to the model under study, $Z = y$.

The orientation of the vector resultant of the forces of destructible material on the front face defines a front cutting angle (δ), a tensile strength of rocks in tension ([σp]) and shear([τ]), elastic-plastic properties of the material being destroyed (μ, E) in the direction perpendicular front face [15]. Therefore the force of resistance to the movement of the cutter in the direction of the front face of the cutter can be represented by a functional relationship:

$$Z_1 = f_2(\delta^z, [\sigma_p]^z, [\tau]^z, \mu^z, E^z)\tag{2}$$

or taking into account the friction resistance on the back face of the cutter:

$$Z = f_2(\delta^z, [\sigma_p]^z, [\tau]^z, \mu^z, E^z) + f_3(Y).\tag{3}$$

The decisive factor in the formation of the load on the front face is the proportion of rock destruction by tensile forces (separation). In the works [15,16], special attention is paid to this physical phenomenon when cutting. It is the implementation of this type of destruction that determines the cutting efficiency and its specific energy intensity. The listed factors in the considered phase of interaction between the cutter and the fracture conditions before the front face are in balance for a moment. In adaptive cutting, this equilibrium can be described by the following functional relationships:

$$Z^1 = Y^1;\tag{4}$$

$$f_1(P^y_k, \mu^y, E^y, F^y_3) = f_2(\delta^z, [\sigma_p]^z, [\tau]^z, \mu^z, E^z) + f_3(Y),\tag{5}$$

where: Z^1, Y^1 – are the instantaneous values of the component cutting forces Z and feed Y.

Thus, the elements of the theory of adaptive cutting revealed a significant difference between the mechanics of the interaction of the adaptive cutter and the mechanics of the interaction of the cutter with the destroyed material during typical cutting. In adaptive cutting, rational cutting parameters are not set, but they are self-determined within limits.

Therefore, a very important aspect of adaptive cutting is to describe the limitations of auto-regulation of the cutting process.

3 Development of an adaptive drive for a drilling machine

One of the main factors determining the need to regulate the parameters and modes of rotational drilling is the strength (strength) of the drilled rock. Therefore, consider the method of automatic control of the feed force depending on the rotation frequency of the drill rod when changing the strength of the drill rock, more precisely, the moment of resistance to rotation, which in turn depends primarily on the specific feed, which decreases with increasing rock strength, and increases with decreasing strength.

Here is an example of one of the first rotary drilling machines with adaptive drive, which implements adaptive cutting.

This is a drilling machine with a hydraulic drive of rotation of the drill rod and a hydraulic drive of rotation that provides the rod feed in the direction of drilling, in which the feed force automatically changes with the change of the torque on the rotation drive [17,18]. Self-regulation of such a machine is provided by a two-differential drive, which reduces the feed speed while increasing the torque. The disadvantage of such machines is a relatively complex and expensive drive, including a mechanical differential.

Another example of a rotary drilling machine with an adaptive drive is a machine in which the feed force also changes depending on the moment of resistance to rotation of the rod. This machine uses an asynchronous motor to rotate the rod and hydraulic cylinders to feed the rod into the face. The hydraulic cylinders are fed with hydraulic fluid through an adjustable throttle controlled by the rotation moment on the drill rod. The technical solution under consideration provides automatic reduction of the feed force when the torque resistance to rotation is overstated above the set value by a relatively simple design solution.

However, the depth of regulation in this technical solution is limited - when the rod is jammed, the feed force is not automatically reversed, but only reduced to a minimum value. In addition, the disadvantage of an automated drive of such a drilling machine is the use of electric and hydraulic motors.

Drilling machines with a hydraulic rotation engine and a hydraulic feed cylinder are also known. The adaptive drilling machine has a relatively simple design: a hydraulic cylinder of a telescopic type and a hydraulic motor that is fixed to the retractable rod of the hydraulic cylinder. To ensure adaptive properties in such a drilling machine, we have proposed its modernization, which gives the drive adaptive properties. The essence of the modernization is that the drive of this drilling machine is made according to a special scheme of connecting hydraulic elements to form two main hydraulic differentials. For rice. 2 shows the hydraulic drive scheme of the drilling machine with adaptive properties.

As you can see in the diagram Fig. 2, the hydraulic cylinder 1 and the hydraulic motor 2 are connected in series, with the spool 5 in the working position (III). In this case, the hydraulic line from the output of the hydraulic motor 2 is connected to the piston cavity of the hydraulic cylinder 1 and to the entrance to the third tuning throttle 9, with increased hydraulic resistance, the output from which is connected to the drain line. The rod cavity of the hydraulic cylinder 1 is also connected to the drain line through the first adjusting throttle 7 and the spool 5.

To the pressure line after the spool 6 the second tuning choke 8 is connected, the output from which is connected to the rod cavity of the hydraulic cylinder 1. to visualize the principle of operation of the developed adaptive drive, we present it in the form of a bridge scheme shown in Fig.3.

As seen in Fig. 3 the first hydraulic differential is formed by the pressure line, the hydraulic motor 2 and the adjusting throttle 8.

The hydraulic line through the throttle 8 creates a counter-pressure in the rod cavity of the hydraulic cylinder 1.

When the torque on the hydraulic motor increases, its hydraulic resistance increases, and the back pressure increases, reducing the feed force.

The second hydraulic differential is the hydraulic cylinder 1, the output link of which is the hydraulic cylinder rod.
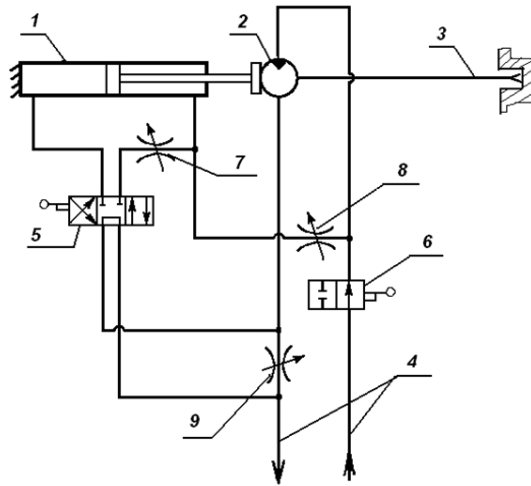

Fig. 2. hydraulic Circuit of the drilling machine drive with adaptive properties: 1-hydraulic cylinder, 2-hydraulic motor, 3-drilling rod, 4-lines to the oil station, 5-three-way spool, 6-two-way spool; 7,8,9-adjusting chokes.

The movement of the rod and the feed force developed by it is determined by the pressure difference in the rod and in the piston cavities. It is obvious that with such a drive scheme, the feed force is regulated by the torque on the hydraulic motor, and the tuning chokes allow you to adjust the degree of such influence. The drive provides adaptive adjustment to rational drilling modes when changing the strength of the drilled rock
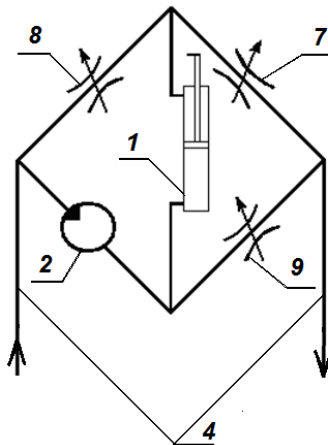

Fig. 3.-Diagram of the adaptive drive of the drilling machine in the form of a bridge : 1-hydraulic cylinder, 2-hydraulic motor, 4-lines to the oil station, 7,8,9-adjusting chokes

Along with the ability to respond to changes in the strength of the drilling material, the considered adaptive drive of the drilling machine has a new quality of automatic reverse in an emergency. For example, when the rod is jammed in the well, the flow through the hydraulic motor will stop and the back pressure in the hydraulic cylinder will rise sharply, the reverse movement of the hydraulic cylinder rod will automatically occur, removing the rod from the bottom until the back pressure in its rod cavity decreases to the nominal value.

In nominal mode, the adaptive drive drilling machine operates as follows. At idle, before drilling, the load on the hydraulic motor 2 will be minimal, and its hydraulic resistance will also be minimal.

As the cutting crown is inserted into the face, the moment of resistance to rotation on the shaft of the hydraulic motor 2 will increase. At the same time, the pressure in the piston cavity of the hydraulic cylinder 1 will decrease to some extent and the pressure in its rod cavity through the adjusting throttle 8 will increase.as a Result, the feed force will decrease to a rational value, which will ensure a reduction in the specific feed and to the calculated value. These changes will provide a reduction in torque on the shaft of the motor to a stable value. Depending on the drilling conditions (rock strength, drilling depth, cutting tool bluntness, etc.), the value of the nominal torque can be adjusted by setting the third line choke 8. The results of modeling restrictions in the operation of an adaptive drilling machine are given in.

4 Conclusions

1. The implemented feed force control provides an increase in the drilling speed, automatic adjustment to drilling modes that are close to optimal;
2. the use of an adaptive drive increases the drilling speed by intensifying the cutting process and increasing the feed force, while increasing the strength of the drilling material or increasing the bluntness of the cutting tool;
3. Adaptive drive for drilling in difficult mining and geological conditions provides maximum performance and automatic protection against overloads at the moment of rotation;
4. The drive control is realized by the thrust force of the torque on the hydraulic motor;
5. Adaptive drive of drilling machines has a relatively simple way to implement it.

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