Self-adjusting differential rotary feeding system of the drilling rig

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Abstract. The article discusses in detail all existing types of self-adjusting rotary feeding systems (RFS) of drilling rigs, analyses their advantages and disadvantages. A kinematic diagram of a self-adjusting RFS of a differential drilling rig is shown, which significantly eliminates the drawbacks of the self-adjusting RFS of drilling rigs discussed above.

1. Introduction
The most important aspect of technical progress in the field of underground and open mining of mineral deposits with high hardness is an expensive and laborious drilling process.

Various drilling rigs are used for drilling, which, according to the method of rock destruction, are divided into two types - physical and mechanical. The first type of drilling machines includes machines for blasting, thermal, hydraulic, electro-hydraulic and ultrasonic drilling, which act on the destroyed rock through a liquid and gaseous medium. Despite the variety of physical and combined drilling methods, mechanical drilling remains the most important.

Significant progress in drilling operations is possible only with the help of the drilling process automation, where the main object of automation is a rotary feeding system (RFS) of the drilling rig, the functional purpose of which is to create the feed force, tool rotation frequency and other parameters, so that in the end, to get the optimum drilling mode, leading to the maximum productivity of the rig. Therefore, automation of the drilling process in the development of modern technologies and equipment [1-39] is the most urgent task.

The systems for controlling the drilling mode parameters can be divided into three groups: software-controlled, search engine and combined. These groups are considered in detail in [40]. Search engine and hybrid control systems have two significant drawbacks that minimize the appropriateness of their use. The first drawback is that the optimum drilling parameters can be determined in a very short period of time, i.e. by the current values, and not by the cumulative criteria, such as productivity and drilling costs. The second drawback is that the time to reach the optimum mode is significant (due to an overabundance of options analysis for finding the optimum control mode) and, ultimately, the drilling mode will never be optimum.

Thus, the most optimum way to regulate the drilling mode parameters is a method using software-controlled systems, which, according to the implementation principle, can be divided into open-loop systems, systems with self-regulation of drilling mode parameters and a feedback system that takes into account the properties of the drilled rock at this particular moment.
2. Main section
Let us consider the most common designs of drilling machines that implement software-controlled drilling mode control systems with self-regulation, the so-called ‘self-adjusting drilling machines’ [40].

Fig. 1 shows a drilling machine with a differential screw developed by A.P. Moskalev [40].

![Diagram of a drilling machine with a differential screw developed by A.P. Moskalev](image)

**Figure 1.** Diagram of a drilling machine with a differential screw developed by A.P. Moskalev
1 – rotator; 2 – pneumatic motor; 3 – carriage; 4 – guide frame; 5 – control device; 6 – spur gear speed reducer; 7 – propeller bolt (screw); 8 – gear nut; 9 – control panel

The drilling machine includes rotator 1 driven by pneumatic motor 2, which has a rigid connection with carriage 3, covering guide frame 4 and freely moving along it, control device 5 connected through spur gear speed reducer 6 with screw 7 forming a kinematic pair with gear nut 8, located in the rotator body and kinematically connected with the spindle of the drilling machine, as well as control panel 9.

The relative rotational speed of the gear nut and the screw, depending on the value of the axial pressure and the moment of resistance, determines the drilling speed. It should be noted that the axial pressure and the moment of resistance depend on drilling conditions and physical and mechanical properties of the drilled rocks.

Fig. 2 shows a diagram of the automatic control of a birotary engine.

![Diagram of an automatic control of birotary engine](image)

**Figure 2.** Diagram of an automatic control of birotary engine

Diagram labelling: \( P_1 \) – speed (gear) reducer; \( P_2 \) – speed (gear) reducer; \( D_1, D_2 \) – birotary engine; \( TЭ \) – brakes (braking system)
The lead screw, fixed in the bed, is driven through $P_1$ reducer and a bushing with keyed projections by the rotor of $D_1D_2$ birotary electric motor, and the feed nut is driven through $P_2$ reducer by the counter rotor. The feed force on the cutting tool is perceived by the braking element, which has a connection with the counter rotor. A decrease in the rotational speed of the cutting tool due to an increase in the moment of resistance, due to an increase in the strength and viscosity of the material being destroyed, entails a decrease in the rotational speed of the lead screw and an increase in the rotational speed of the feed nut. As a result, the feed rate of the tool tends to the value at which the initial ratios of the rotation moments on the cutting tool and the feed nut, predetermined by the kinematic and design features of the machine, are provided.

A double differential drive received great advancement after the development of hydro- and electric machine differentials (HMD and EMD), where two fixed hydraulic motors and two DC and AC electric motors are used. Fig. 3 shows a diagram of a drilling rig with a hydraulic machine differential. A two-motor hydraulic drive acquires the properties of a differential if hydraulic motors $GD_1$ and $GD_2$ are connected in parallel.

![Figure 3. Diagram of a drilling rig with a hydraulic differential](image)

Diagram labelling: $P_1$ – speed (gear) reducer; $P_2$ – speed (gear) reducer; $GD_1$ – hydro motor; $GD_2$ – hydro motor

Fig. 4 shows a diagram of a drilling rig with HMD and a piston hydraulic feed, implemented in a drilling rig for drilling with a diamond disk tool.

![Figure 4. Diagram of a drilling rig with a hydraulic differential and a hydraulic piston feed](image)

Diagram labelling: $D_1$ – electromotor; $K$ – spur gear differential carrier; $P_1$ – gear reducer; $H$ – pump; $GD_1$ – hydro motor; $GD_2$ – hydro motor

In the diagram, the disk tool is rotated relative to its axis by $D_1$ electric motor, and relative to the well axis - by the carrier of gear differential $K$ through $P_1$ reducer. From $P_1$ reducer, power is taken to pump $H$ of the piston feeders, which synchronize the feed with the tool rotation frequency relative to the well axis. The properties of automatic regulation of the operating mode depending on the drilling conditions (up to the retraction of the tool) are characteristic of all drilling machines with a double differential drive.

Fig. 5 shows a kinematic diagram of a differential type rotary feeding system of a drilling rig.
Figure 5. Kinematic diagram of a differential type rotary feeding system of a drilling rig.
1 – drilling assembly; 2 – rotary drive; 3 – feed drive; 4 – common motor $D_1$;
5 – cone differential; 6 – control motor $D_2$

This diagram makes it possible to automatically control the force and feed rate due to the feedback between drilling assembly 1, rotary drive 2 and feed drive 3, using common motor 4. The said feedback is carried out through cone differential 5. Control motor 6 allows to determine the range of variation of the controlled parameters above. The presented scheme contributes to a significant reduction in dynamic system overloads, vibrations and other negative effects.

3. Results

The above diagrams of self-adjusting drilling machines basically include all the diagrams that were used in the development of drilling machines of this type. These diagrams, in addition to advantages, also have disadvantages. Thus, machines with a differential screw, due to the complexity and high cost of manufacturing the screw, have a small feed stroke, as well as the transmitted power through the drilling assembly is relatively small, the low efficiency of the screw drive should be noted.

Drilling machines with a birotary engine have a common disadvantage - the ability to automatically change only the feed rate with a limited range of tool rotation speed control.

Hydraulic self-adjusting drilling machines, for example, machines with HMD, along with the main advantage - a deep change in controlled parameters during implementation of significant capacities, have the main disadvantage - unproductive energy losses characteristic of the throttling control method.

The most complete compliance with the optimum criteria that determine the positive ratio of the complexity of self-adjusting drilling machines’ design and the level of their maintenance at mining enterprises, as well as a very high cost of manufacturing the machines, to the advantages that the automation of the drilling process with these machines provides, is inherent in the differential type RFS (Fig. 5). However, this diagram also has some disadvantages:

1) a self-braking worm gear, the functional purpose of which is to exclude the possibility of a power flow transition from the system to the control motor, has a low efficiency ($\eta < 0.5$);
2) a large mass of moving parts of the worm gear increases the inertia of the system, which increases the response time of the system to signals received from the working body of the machine; 3) high cost and complexity of manufacturing of a worm gear pair.

Below is a kinematic diagram where these disadvantages are absent.

Fig. 6 shows a kinematic diagram of a self-adjusting rotary feeding system of a drilling rig.

**Figure 6.** Kinematic diagram of a self-adjusting rotary feeding system of a drilling rig

1 – drive; 2, 3, 4, 5, 6, 7 – gear wheel system; 8 – gear reducer; 9 – assembly; 10 – control system drive; 11 – freewheel clutch; 12 – cone differential; 13, 14 – conical gear wheels (bevels); 15 – carrier; 16, 17 – conical gear wheels (bevels); 18, 19 – conical gear wheels (bevels); 20, 21 – drive shafts; 22 – gear wheel; 23 – gear rack

Diagram labelling:

$M_{D1}, M_{D2}, M_{C}$ - moment of force of rotary drives, control drives and resistance drives to the rotating assembly;

$M_{15}, M_{20}, M_{21}$ – moment of force;

$F_O, F_C$ – driving force and resistance force of the assembly movement in the massive rocks;

$V_R, \omega_C, \omega_{D1}, \omega_{D2}, \omega_{15}, \omega_{20}, \omega_{21}$ – feed speed and angular velocity of the assembly, motors $D_1, D_2$, carrier 15, drive shafts 20 and 21 of the differential.

The difference from the diagram shown in Fig. 5 consists in the fact that instead of a massive, expensive worm gear, the functional purpose of which is to exclude the possibility of a power flow transition from the system to the control motor, a light oversized flyback clutch is used, which performs the same functional purpose.
The mechanism works as follows. Motor 1 rotates drilling assembly 9 through the system of gears 2, 3 and 4, 5, as well as the left axle shaft of differential 21 and the output link of feed mechanism 22 through conical pair of wheels 13-14, carrier 15, conical pair of wheels 16-19. The gear wheel 22, rotating with an angular velocity $\omega'_{22}$, moves the entire mechanism located on carriage 25 along the guides of frame 24 towards the rock mass - creates an axial force $F_0$. When control motor 10 is off, the right semi-axle 20 of the differential and wheels 18 are stationary, rotation from motor 1 to semi-axle 20 is not transmitted, since the functional purpose of the overrunning clutch 11 and the worm gearbox are the same, as we have already mentioned above. The movement from control engine 10 through overrunning clutch 11, differential 12 is transmitted to the left axle shaft 21 and output link 22 of the feed mechanism, the angular velocity of which is $\omega''_{22}$. In this case, the gear wheel 22, rotating at an angular velocity $\omega''_{22}$, moves the mechanism away from the array. The resulting movement of output link 22 of the feed mechanism is determined by the difference $\omega_{22} = \omega'_{22} - \omega''_{22}$.

4. Conclusions
The article discusses the existing systems for controlling drilling parameters. It is determined that the most widely used at the moment are machines that implement software-controlled systems for controlling the parameters of the drilling mode.

The diagrams of self-adjusting drilling machines are considered, which cover the whole range of machines of this type. It is determined that the most optimum for a drilling rig is a differential type rotary feeding system.

The diagram of the self-adjusting rotary-feeding system of the drilling rig is proposed, the design and the principle of its operation are considered.

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