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PERFORMABILITY OF ELECTRO-HYDRO-MECHANICAL ROTARY HEAD OF DRILL RIG IN OPEN PIT MINING: A CASE-STUDY

Introduction

Vibration induces fatigue fractures, causes damages and failures of drilling equipment, exercises ill effect on operating personnel and increases expenses connected with maintenance of drill rigs. With higher power supply capacity and dynamic stress of the drive, the energy losses also grow [14]. For instance, under strong vibrations, the energy spent for generating a net torsion torque of a drill rig reaches 40–50%. A considerable portion of the drill rig drive capacity is under-used as a result.

At NUST MISUS' College of Mining, at the Mining Equipment, Transport and Machine Engineering Department, an electro-hydro-mechanical rotary head has been designed for drill rig model SBSH-250MNA-32. Owing to rational dynamic characteristic of the transmission, the rotary head design enables reducing vibrations, increasing longevity and, as a consequence, enhancing efficiency of the drill rig.

This study aims to improve the electro-hydro-mechanical rotary head and its reliability.

Problem formulation

For better suppression of drill rig oscillations because of vertical displacements of the drill string, it is provided to install up-dated feed cylinders to operate concurrently with the hydromechanical rotary head.

Reduction in vibration of the rotary head results from its redesign and elimination of shortages [8, 12, 13], including:

- substantial friction in seals of piston and rod in feed cylinders: the total friction force in the seals in two feed cylinders at the pressure of 10 MPa ranges as 6–9 kN;
- impossible displacement of the cylinder piston in the opposite direction to its power stroke in the impulsive loading of the drill string in the vertical plane.

The current operation of drill rig model SBSH-250MNA-32-32 shows that only the piston seal assembly works in satisfactory conditions.

Sealing of the rod surfaces in the cylinders is inappropriate, and the surfaces become covered with a network of longitudinal scratches to 0.5 mm deep in a short time. As a consequence, the service life of the seals is drastically reduced down to no more than 200 double strokes. In the meanwhile, standard seals should ensure more than 500 thousand double strokes in normal operating conditions.

It is required to install fluoroplastic seals in new cylinders, or in cylinders with reconditioned surfaces, with obligatory protection of the rod from the abrasive environment.

Free travel of cylinder piston 1 is ensured when the piston

The test subject is the electro-hydro-mechanical rotary-and-feed mechanism of roller-bit drill rigs with undermount rotary head.

The goal of the research is the capacity stimulation, vibration reduction and reliability improvement of drill rig model SBSH-250MNA-32.

The article describes the studies in the field of mining machines and the relevant engineering solutions.

It is critical for Russia to preserve and replenish its mineral resources and mineral reserves to pursue social and economic advance. The priority growth of coal and gold production using the advanced open pit mining method can increase percentage of the latter in cumulative mineral mining by not less than 50%. Furthermore, it is necessary to cut down costs of production by 4–5%.

The main and extremely labor consuming process in open pits in Russia is drilling which takes up to 40% of total mining cost [1–3].

The common method of drilling in rocks with the hardness factor of 6–20 on Protodyakonov's scale in Russia is the roller-bit drilling [4–6]. This drilling processes is accompanied with high dynamic loading imposed on the rotary-and-feed mechanism [7–9].

One of the ways of reducing dynamic loads in the roller-bit drill rigs is redesigning of the rotary-and-feed mechanism to possess higher safety and anti-vibration properties, simpler structure, as well as better performability and longevity [7, 8, 10–13].

This article describes and substantiates the design and operating principle of the electro-hydro-mechanical rotary head, its prototype testing, the research program and procedure, the instrumentation preparation, the research objective as well as the test data processing and analysis as a case-study of drill rig model SBSH-250MNA-32.

Keywords: drill rig, dynamic parameters, hydraulic cylinder, hydropneumatic accumulator, reliability, electro-hydro-mechanical rotary head

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cavities are connected with hydropneumatic accumulators 2 (**Figs. 1 and 2**).

The accumulators may be equipped with a piston or with a flexible separator. The latter are preferable. In the piston-type accumulators, the friction forces in the piston seals and the mass of the piston limit the application range as compared with the accumulators with a flexible separator. The accumulators are filled with nitrogen to ensure explosion safety and to reduce corrosion of walls.

The highest reduction of vertical vibrations is achieved when the hydropneumatic accumulators with a flexible separator (capacity of 2.5 l and more, charge pressure $P_{\text{work}} = 0.7 \div 0.8$ MPa) are integrated with the modernized feed cylinders.

When connected with the base feed cylinders, efficiency of the accumulators drops.

Thus, connection of the accumulators to the rod cavity of the hydraulic cylinders improves compliance of the drill rig feed by more than 25% and is independent of the drilling depth (number of drill rods).

Research methodology

The industrial tests revealed deficiencies in the rotary head

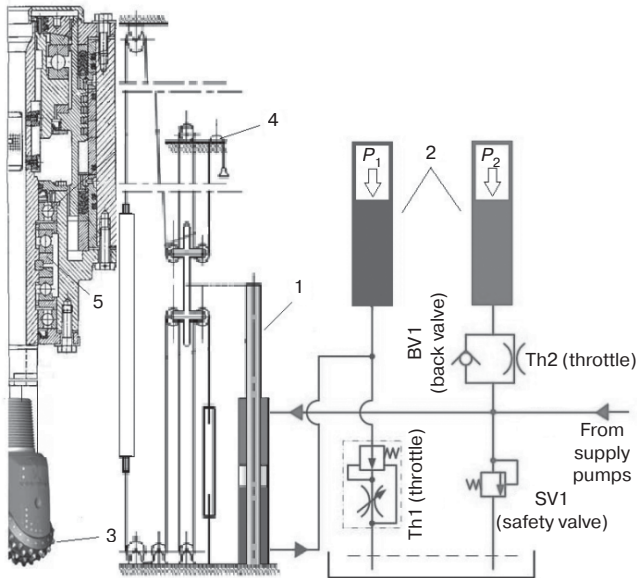


Fig. 1. Hydraulic circuit diagram of new feed system of drill rig rotary head in drilling:

1—hydraulic cylinder; 2—hydropneumatic accumulators; 3—tricone bit; 4—block and tackle; 5—drill rig

design, which required to:

- install additional seal groups in the cover of the hydromachine;
- ensure forced lubrication in the planetary insert in the rotary head;
- provide independent feed of the hydromachine;
- develop a hydraulic control unit to ensure operation of the drive in all modes;
- install the hydraulic control unit in the engine space of the drill rig;
- arrange the hydropneumatic accumulators on the back wall of the drill rig tower and to connect them to the piston and rod cavities of the feed cylinders;
- redesign the feed cylinders and to fit them with the low friction seals.

These are the measures accomplished to modernize the electro-hydro-mechanical rotary head of drill rig model SBSH-250MNA-32.

Research program, procedure and instrumentation

Research objectives

The objectives of the experimental research of drill rig model SBSH-250MNA-32 with the electro-hydro-mechanical rotary head include:

- a) reduction in the drill rig vibrations and in the dynamic loads in the rotary head transmission;
- b) stimulation of drilling using the electro-hydro-mechanical rotary head and determination of the rational operating conditions;
- c) estimation of impact exerted by the torsional vibrations of the rotary head transmission on the vertical vibrations of the drill rig.

The experimental research findings should offer ground for the design guidance for rotary heads and rotation-and-feed mechanisms, and for selection of capacities and charge pressures of hydropneumatic accumulators.



Fig. 2. Connection of hydropneumatic accumulator to main line of redesigned feed cylinders of drill rig model SBSH-250MNA-32

Testing routine

Stage I—Operation without the electro-hydro-mechanical rotary head (power-operated feed).

Stage II—Installation of the electro-hydro-mechanical rotary head.

Stage III—Installation of retrofit feed cylinders.

Each stage includes:

1. Idle speed testing of the drill rig for the functional check of all mechanical groups, hydraulic drive, transmission, pneumatic system, dust collector, electric equipment and automatic electric drive, as well as for verification of setting up and debugging.
2. Load testing to determine:
 - serviceability of the rotary head and the rig, including full loading;
 - maximum possible capacity of the drill rig;
 - longevity of the drilling tool;
 - energy input and consumption of materials in drilling;
 - time consumption in the main and auxiliary operations of drilling, and their specific weights in the total action time schedule;
 - compliance of the drill rig design solution with the effective safety standards;
 - compliance of the drilling technology and machinery with the effective standards of occupational health;
 - design deficiencies to be eliminated.

Testing procedure

The electro-hydro-mechanical rotary head efficiency criteria are assumed to be: the impact accelerations, the penetration rate and the capacity of the drill rig. On the strength of these criteria, the set of parameters to be recorded and measured is determined, namely:

- the type and hardness of rocks being drilled;
- the acceleration amplitude of the drill rig in the vertical plane;
- the acceleration amplitude of the drill rig in the horizontal plane along the longitudinal and transversal axes of the drill rig;
- the electric motor current;
- the electric motor voltage;
- the pressures in the high-pressure main line of the hydraulic machine;

- the rpm of the drilling string or the transmission component set in the kinematic circuit behind the planetary gear;
- the pressure in the piston cavities of the feed cylinders;
- the longevity and wear mechanism of the drill bits;
- the drill rig capacity.

The measurements are taken using the analog checkout equipment; its use procedures and efficiency are discussed in [14–23].

1. Recording is carried out by analyzers VIBXPART II, Topaz and Quartz.

2. The electrical parameters of the motor are measured and recorded using the common schemes, without special sensors.

3. The rpm and advance velocity of the drill rig are measured using analyzers VIBXPART II, Topaz and Quartz.

4. The pressures in the main line are measured by remote sensors TMD-100, TMD-150 and TMD-250.

The control over variation in I_{ab} , V_{CT} , V_{ab} and P_{ax} uses pointer indicators arranged in the drill rig operator's cab, and the changes in the main line pressure are traced using manometers MN1 and MN2 arranged in the hydraulic unit.

The varied parameters in the tests are:

- the drilling string rpm—range of 50–150 min^{-1} ;
- the axial force—range of 10–24 kN;
- the charge pressure of the hydropneumatic accumulator in the high-pressure main line of the machine—range of 0.3–0.9 P_{NOM} .

The measurements should be taken mostly at the drilling string rpm more than 100 and at the axial pressure more than 20 kN, for the reliable verification of the forced drilling practices.

Testing plan

The testing plan includes some work performed in the factory conditions, namely:

- preparation and calibration of the remote pressure sensors, and manufacture of the proper hydraulic fittings;
- static calibration of vibration analyzer VIBXPART II;
- assembly and calibration of meter circuits for voltage and current of the rotary head motor and for advance velocity of the drilling string;
 - calibration of VIBXPART II to measure rpm of the drilling string;
 - design and manufacture of the attachment points for VIBXPART II and sensors DUS-5.

Test stage I is implemented in an open pit, with arrangement of the drill rig with the rotary head and feed cylinders; analyzer VIBXPART II, and the pressure and acceleration sensors; with connection of the measurement and recording instrumentation to the drill rig control circuit; and with checking and final calibration of the measurement and recording equipment;

Test stage II includes:

- assembly of the rotary head and hydraulic unit on drill rig model SBSH-250MNA-32;
- connection of the hydraulic unit and fluid-power motor IMP2.5 to the hydraulic system of the drill rig.

At each test stage, the modernized feed cylinders are set on the drill rig, and the hydropneumatic cylinders (see Fig. 1) are connected with the piston cavities of the cylinders.

The experimentation procedure is described below.

1. Measurement and recording of the test parameters is carried out:

- in pre-drilling;
- in drilling with the second drill rod;

- at the end of drilling, at the full length of the drill string.
2. In the course of a record by VIBXPART II (oscillography), the readings of the point indicators installed in the operator's cab and in the hydraulic unit, and the shift capacity of the drill rig are entered in an observation log [18, 20, 21].

Processing and analysis of testing data

The sensor readings were recorded by VIBXPART II in drilling at the depths of 5–7, 9–11 and 14–17 m, with the standard and new rotary head. The testing involved 21 drilling modes, including 9 modes with the standard rotary head and 12 modes with the redesigned rotary head.

The analysis of VIBXPART II data demonstrated piecewise in Fig. 3 shows that inclusion of the rotary head in the transmission of the machine with installation of the hydropneumatic accumulator with the charging pressure set in conformity with the rotary head motor load enables a heavy drop in the dynamic loads transferred from the drive to the metallic structure of the drill rig.

Especially appreciable is the decrease in the vibration accelerations in the horizontal plane along the transversal axis of the drill rig frame (curve 1).

For example, the maximum vibro-accelerations A_x are 3–3.5 m/s^2 before installation of the hydromachine and 2.1–2.4 m/s^2 after the installation, and the highest reduction takes place at the lower frequencies, which is explained by the disparity of the free and exciting frequencies in this zone (2.2 and 6.4 Hz). Similarly, the maximal vibro-accelerations A_y in the horizontal plane along the longitudinal axis of the drill rig decrease from 1.8–2.2 m/s^2 to 1.35–1.6 m/s^2 and A_z in the vertical plane lower from 3.9–7.8 m/s^2 to 3.6–5.7 m/s^2 . All these values were obtained at the same torsion torques ($I_{ab} = 70\text{--}80$ A), rpm ($n = 120\div 140$ min^{-1}) and feed forces ($P_{ax} = 14\div 18$ kN).

In drilling without the hydromachine, vibrations at the frequencies of 2.18–2.21 Hz, 6.4–6.6 Hz, 13.1 Hz and 77–80 Hz are especially pronounced; and two of these frequencies are present in the record of the vibro-accelerations and in the record of the motor armature current.

It is found that the key source of vibrations is the drill bit–face rock interaction and the deviation from the drill rod geometry:

- frequency of 2.18–2.21 Hz agrees with the drill string rpm;
- frequency of 6.4–6.6 Hz conforms with the drill bit interaction with the three-wave bottomhole surface;
- frequency of 13.1 Hz is divisible by the frequency of interaction with the three-wave bottomhole surface.

Frequencies of 77–80 Hz generated by the drill bit–bottomhole interaction slightly contribute to vibrations of metallic structures of the drill rig, at the level not higher than 15–20%.

The record of the motor current almost lacks vibrations at the frequency of 2.18–2.2 Hz and contains weak vibrations at the frequency of 6.4–6.6 Hz, because of the free frequency shift toward the lower frequencies at the cost of additional compliance, and owing to the motor work in the post-resonance zone. The values of the exciting frequencies in this case essentially exceed the free frequencies, which results in reduction in amplitudes of vibro-accelerations by 30–40%.

The drilling stimulation tests included increase in the rpm, motor loads and feed forces of the modernized electro-hydro-mechanical rotary head up to the vibro-accelerations achieved in the tests of the drill rig without the hydro-machine. It is found that the drill rig rpm grows by 13–15% (to 150–160 min^{-1}) and the feed force increases by 11–18% (to 17–20 kN), which enhances the penetration rate by 12–15%.

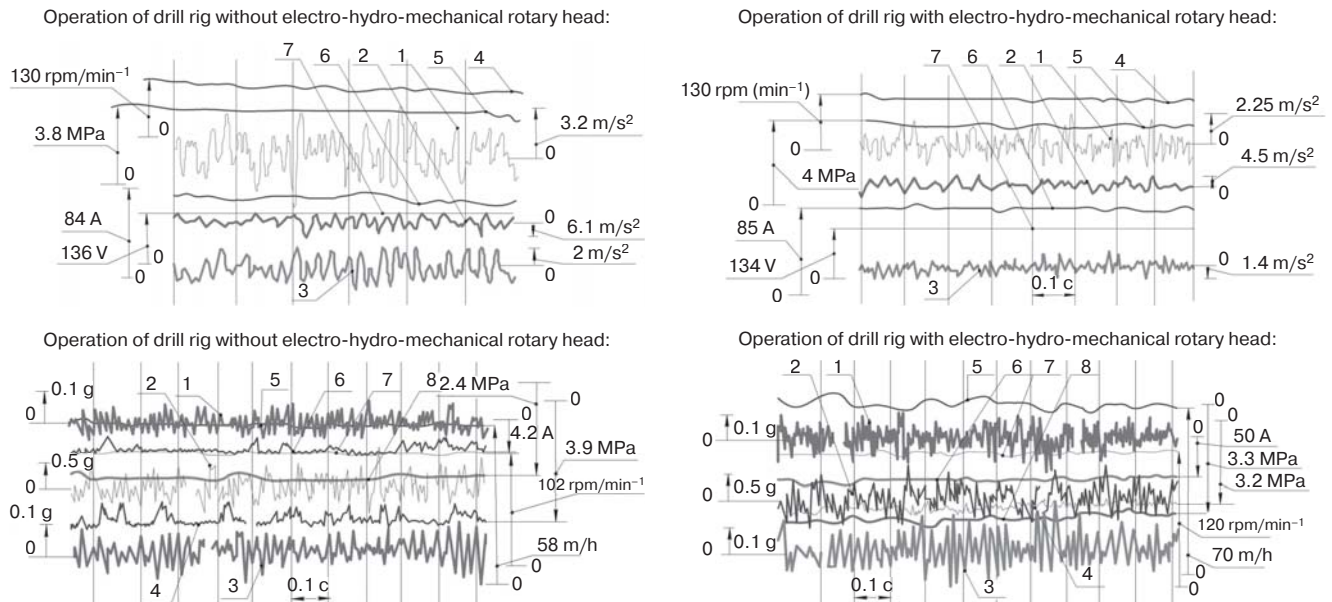


Fig. 3. Piecewise readings of universal vibration analyzer VIBXPERT II:

1—acceleration in horizontal plane (along frame); 2—acceleration in vertical plane; 3—acceleration in horizontal plane (across frame); 4—pressure in piston cavities of feed cylinders; 5—penetration rate; 6—motor current; 7—drill string rpm; 8—pressure in supply main of hydromachine

Conclusions

Based on the findings of the research implemented by the authors, the electro-hydro-mechanical rotary-and-feed mechanism has been designed and tested. The relevant utility patent application is prepared. The electro-hydro-mechanical rotary-and-feed mechanism represents a brand-new design of the drilling tool drive transmission and the modernized feeding mechanism.

The tests of the pilot electro-hydro-mechanical rotary-and-feed mechanism have found out that:

1. The electro-hydro-mechanical rotary head with rational dynamic parameters:

a) effectively minimizes dynamic loads in the drilling tool, in the drive and in the metallic structures of the drill rig;

b) is advantageous over the standard hydro-drive owing to:

- double reduction in installed capacity;
- no double conversion of energy;
- simple structure;
- essentially longer service life of the machine because of operation in braking conditions;


c) ensures reduction in vibrations (the decrease of the amplitude of the drill rig frame vibro-accelerations in horizontal and vertical planes reaches 30–40%);

d) enables stimulation of drilling modes and enhancement of the drill rig capacity in the forced drilling modes in hard rocks; in this case, the same amplitudes of vibro-accelerations as on the drill rigs without the electro-hydro-mechanical rotary head are achieved at the penetration rate higher by 12–15%.

2. The efficient reduction in vertical vibrations of the drill rig is a result of modernization of the feed cylinders, which allows lower friction between the cylinder walls and pistons and rods, and is a consequence of connection of the hydraulic main lines with the hydropneumatic accumulators with a capacity of 9.5 l and with a charge pressure value selected from the range $P_{\text{charge}} = 0.7 \div 0.8 P_{\text{work}}$.

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THE USE OF FREQUENCY CONVERTER AND ACTIVE RECTIFIER OF VOLTAGE FOR THE POWER QUALITY IMPROVEMENT IN COAL LONGWALLS

Introduction

Enhancement of productivity and performance in coal longwalls is achievable via transition to longwalls up to 250–400 m long and by increasing installed capacity of longwall machine system [1, 2]. For example, it is succeeded to raise the rated capacity of SL shearer-loaders to 1200–2200 kW and of scrape conveyors Anzhera 38 and PF 4/1032 up to 1600–2500 kW. Capacities of scraper loaders, crushers and pump-stations are also being increased.

Longwalls are powered by central underground substations via 6 kV cable lines to 5–8 km long. The operating experience of scraper conveyors with head and tail power units composed of 3–4 hauling blocks having capacity of 400–630 kW, with induction motor–hydraulic coupling or with two-speed induction motor shows that

Improvement of productivity and performance in coal longwall mining is achievable via transition to longwalls to 250–400 m long and by increasing installed capacity of longwall equipment systems up to 4200–5600 kW. The up-to-date longwall mining uses energy- and resource-saving machines equipped with variable frequency motors. In this case, inclusion of the frequency converters in the machinery electrics results in essential distortion of voltage from the nominal sine waveform and leads to the power quality degradation in longwalls. With a view to enhancing power quality in longwall networks, the authors propose to use variable frequency motors with frequency converters with active rectifiers of voltage.

When selecting a frequency converter with the active rectifier for voltage in underground power network, it is recommended to take into account the longwall power supply specifics, the cross-effect of the frequency converters operating in neighbor lines, the variable nature of power system loads and the change in the number of the frequency converters in simultaneous operation. To that end, the power supply model is developed to study consumed power quality with regard to the power network topology, parallel-operating frequency converters and actual loads of electric motors. The modeling has determined the mechanisms of effect exerted by the frequency converters on the power quality in operation with active rectifiers of voltage. The carrier frequency and inductance of the buffer reactor of the three-level active rectifier, which ensure the standard quality power supply in longwall, are substantiated.

Keywords: Longwall, longwall mining system, variable frequency motor, total voltage harmonics factor, voltage distortion, active rectifier of voltage, modeling

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