Choice of materials and justification of the parameters for the over-bit hammer

D A Iungemeister¹, R I Korolev¹, A I Yacheikin¹, A I Isaev¹

¹ Department of Mechanical Engineering, Saint-Petersburg Mining University, 21-Ya Liniya Vasil’yevskogo Ostrova, 2, St Petersburg, 199106, Russia
E-mail: iungmeister@yandex.ru, rom8592009@yandex.ru, a.krup53@mail.ru

Abstract. Currently, there is a lack of efficiency of intensification of the rotational drilling process. Therefore, it is proposed to amplify it with shock loads by installing a downhole hammer (DH) into the rig’s drilling assembly, for instance, SBSh-250. In addition, the PPU changes the impact system by placing between the piston-striker and the drilling tool, an intermediate element of smaller mass and size – the striker made of a special Al-Ti alloy. At the same time, it is assumed that the drilling tool will be reinforced with tungsten carbide WC and other high-strength materials. Besides the SBSh-250 machines, shock loads can be applied to disk cones used in tunneling complexes. In this case, the oscillation generator should be placed together with the disk roller cutter into the body of the rotary actuator. The article also discusses the issue related to the choice of bearing material operating under high shock loads. The proposed constructions of rock-cutting tools are calculated in the process of experimental studies in a manner that the increased impact energy does not influence the durability of the working tool and the elements of the DH impact system (selection of high-strength material for making the striker). Having selected the necessary parameters using a test stand, the improved drilling system will allow one to increase the drilling speed (productivity) by 20–30 %, to increase the speed of tunneling with the installed vibroactive disk rolling-cutter by 25 %, and also to extend the operational life of the working tool.

1. Introduction

The practice of domestic, much cheaper, drilling equipment allows you to organize the process by using multimachine manning of equipment and it has a great influence on social aspect, as it allows one to load domestic mining engineering plants, as well as to create new job opportunities in production.

The main directions of improving roller-bit drilling rigs are to increase the drilling speed by automating the control of operational parameters or using various technical means of intensifying drilling and reducing the vibration of the drill stand and the machine as a whole [1–3].

One of the main points is developing engineering tools to improve the productivity of locally produced roller-bit drilling rigs while maintaining the endurance of the rock cutting tool and decreasing the drill stand’s vibration.

Options of modernization is of high priority in terms of environmental impact (human), and this is an important and correct priority, indicate the need to decrease the level of harmful component vibration of the drill string. It can be achieved by the following means [6]:

• installation of damping devices (hydraulic shock absorbers) between the drill string and the rotator head or between the rope and the supply hydraulic cylinder;
2. Increasing the intensification of roller cone drilling machines

The purpose of the DH installation is to increase the drilling speed. A preliminary morphological analysis of the drilling stimulation process, conducted by experts from Mining University and specialists from manufacturing enterprises, has shown that in order to improve roller-bit drilling rigs according to the minimum version, it is advisable to use the DH with shock damping and the formation of an “L”-shaped shock pulse.

Specific drilling rig schemes with a shock mechanism for a given pulse shape can be realized by creating hollow piston-drums with a special filling, for example, a heavy magnetoactive fluid with low viscosity, which is technically very difficult to implement. The purpose is achieved by solving the following tasks:

• using of the shock system "piston – striker – tool" (Figure 1) to intensify the introduction of pins into the rock during its destruction;
• chipping of roughnesses of the bottom hole to improve the fit of the bit to the bottom hole, decreasing the dynamics of the drill string, increasing to the maximum simultaneous destruction of the bottom hole with bit inserts;
• decreasing the impact on the destruction of the bottom hole by the presence of particles (culm);
• increasing the durability of the bit and equipment.

The problem can be solved by installing the DH with rational parameters and dividing the shock pulse (shock force) into subpulses when using the striker in the "chatter" mode (Figure 1) [1, 2, 5]. The effectiveness of DHs with the striker is tested at the bench during experimental studies.

To evaluate the proposed device (DH with the striker), it is necessary to calculate the main parameters of the shock system operating in the rotary-shock drilling mode. To carry out this study, it is necessary to determine the maximum axial force, depending on the operating conditions of the machine. However, an important task is finding other materials to replace tungsten carbide.

We must mention that an important problem is the resistance of the cones on the cone, as well as the resistance of the hammer [7]. As a material for the manufacture of bit inserts, it is supposed to use tungsten-cobalt alloy, or WC tungsten carbide, which has high strength, hardness (90 HRC) and wear resistance. The hammer, in our opinion, must be made of special Al-Ti alloys that will meet the required parameters: increased service life and durability, as well as facilitating the entire installation [8].
Using shock load to destroy the rock mass is relevant not only during drilling, but also in the destruction of the bottom hole by disk rolling-cutter used in modern tunneling complexes when driving tunnels and auxiliary workings [9], in difficult mining and geological conditions for the construction of the St. Petersburg metro.

A distinctive feature of the mountain geological conditions of St. Petersburg is a very heterogeneous bottom hole massif, represented by Cambrian clays with inclusions of granite boulders, granite pebbles, as well as numerous interlayers of limestone and sandstone [10]. Modern tunneling complexes Herrenknecht with hybrid rotary actuators cannot effectively destroy the combined mining face, which is confirmed by the low penetration rate and emergency failure of the rock cutting tool (Figure 2).

**Figure 1.** Roller bit with drummer. 1 – piston; 2 – striker; 3 – roller bit; 4 – roller cone; 5 – bit insert

**Figure 2.** Wear of the disk rolling-cutter.
3. The imposition of shock load
The experimental use of vibroactive rock cutting tools was carried out at the Mikhailovsky mine of the Zheleznogorsk GOK with the use of roller-bit drilling rigs (SBSh-250) with electric vibrators. When vibration was applied to the entire surface of the mining face, an increase in the productivity of the SBSh machine was found to be 1.5–2 times and drill bit resistance up to 28 % [11]. Therefore, in order to increase the efficiency of the destruction of solid inclusions, it is proposed to replace the disk rolling-cutter installed on the rotary executive body of the S-782 tunnel boring complex with vibratory ones. It is assumed that the use of such cones on the rotary executive body of the tunnel boring machine will increase the penetration rate to 25 %.

Figure 3 shows the construction of the vibroactive disk rolling-cutter. When the disk rolling-cutter 1 interacts with solid inclusions, the end sensor 4 activates the oscillation generator 3. The oscillations are transmitted through the disk rolling-cutter installed on the rotor of the tunneling machine 2 to solid inclusions, as a result of which they are destroyed.

![Figure 3. Vibroactive disk rolling-cutter design.](image)

When such disk rolling-cutter rolls over along the mining face, chipped rocks are formed, as well as a fractured face structure, as a result of which the cut face becomes less durable. Therefore, in addition to reducing the risk of breakage of the rock cutting tool, the cutting force on the cutters is reduced by 20–30 %.

In this case, a very important issue is the material from which the disk and disk rolling-cutter bearings will be made. Under the influence of shock loads, using rolling bearings is impossible, in view of their rapid failure. Therefore, it is proposed to use sliding bearings made of materials capable of withstanding high shock loads and high antifriction properties. These materials include lead bronzes, tin bronzes, tin-zinc-lead bronzes. The disk is made of alloy steels 35KhGSA and 40KhNMA as standard. These materials do not always meet the reliability requirements, as evidenced by their rapid wear when interacting with hard rocks (Figure 3). The imposition of an impact load will lead to an even faster failure of the cone disk. Therefore, it is assumed that the use of alloys based on tungsten and cobalt for the manufacture of the disk will significantly increase its strength and wear resistance.

To conduct experimental studies of the impact of shock load on the studied rock sample, 3 stands were designed (Figure 5):
- drilling wells using a three-roller bit;
- during the destruction of the rock by rolling in the disk rolling-cutter.
Figure 4. Stand models. Parts of the model (a): rock sample – 1, three-roller bit – 2, rotation head – 3, jackhammer – 4, springs – 5, guides – 6. Parts of the model (b): a tripod – 1, a rock sample – 2, a bed – 3, a rotation head – 4, a jackhammer – 5, a chain hoist – 6.

Figure 4 shows the models of stands. In model (a) springs 5 used to clamp roller bit 2 with rotation head 3 and jackhammer 4 to the test sample of rock 1 have the disadvantage that there is no constant axial force Poc. In model (b) a chain hoist 6, which serves to clamp the bed 3 with the rotation head 4 and with a jackhammer 5, has drawbacks consisting in the difficulty of controlling the constant axial force Poc and the large dimensions requiring a large laboratory. In addition, for conducting experimental studies at stands No. 1 and No. 2, a supply of water or compressed air is required to remove drill fines, which in turn makes it difficult to conduct an experiment in a university laboratory. Therefore, experimental studies were carried out at stand No. 3 (Figure 4c, d), including a three-roller bit or a model of the disk rolling-cutter – 1, drill pipes – 2 and 6, a pile – 3, a body – 4, a TSS-GJH95 gasoline breaker – 5. This unit joins the Geomachine Oy GM-200 drilling rig.

At present, during experimental studies when drilling wells with a three-roller bit without imposing shock loads in the nominal mode, the drilling speed was 0.25 mm/s (Figure 5a, b; 6).

Figure 5. Investigations of drilling a well with a three-cone bit without imposing an impact load (a, b) and imposing an impact load (c).
As it is illustrated in Figure 6, when drilling with a high shock load, an insufficient resistance of the design of the checkered bit to shock loads was revealed. Therefore, it is necessary to pay special attention to the selection of high-quality materials from which the nodes of the three-roller bit are made, so that the durability of the bit is acceptable.

Figure 7 demonstrates an analytically constructed graph of the expected increase in the rate of penetration of dry clays with strong interlayers in the conditions of the St. Petersburg Metrostroy depending on the strength of the rock and the cone tool used: St – disk rolling-cutter; 1 – toothed rolling-cutter; 2 – the vibroactive disk rolling-cutter.

It is assumed that when using gear cones, the increase in penetration rate will be 10–15 %, and when using the vibroactive disk rolling-cutter, it will increase by 20–25 %.
4. Conclusion
The main and promising direction in the field of roller-bit drilling can be the imposition of shock loads on the three-roller bit. The most reliable way to implement shock loads can be the use of the downhole hammer.

In addition, the use of dual impact systems with an intermediate striker will further improve the process of impact-rotary drilling. As design studies and calculations demonstrate, as a result of modernization of the SBSh-250, an increase in the drilling speed and an increase in the service life of the elements of the shock system should be expected. Theoretical studies of the imposition of shock loads on disk rolling-cutter of tunnel boring machines have also shown an increase in penetration rate. However, the calculated indicators must be checked in real conditions. Particular attention should be paid to materials for the manufacture of the three-roller bit and a disk rolling-cutter experiencing high shock loads. Material selection plays a key role in the reliability and cost of rock cutting tools.

Having selected the necessary parameters using an experimental stand (research is ongoing), an improved drilling system will increase the drilling speed (productivity), tunnel penetration rate, extend the life of the working tool, and significantly improve the working conditions of the maintenance staff.

References
[1] Jungmeister D A, Korolev R I, Karlov V A 2018 Improvement of shock system of hydraulic drill to increase drilling intensification IOP Conf. Ser. Earth and Environmental Sci. 194(3) 032006.
[2] Babitsky V I, Sokolov I J, Halliwell N A 2009 Foundations for design of vibro-safe hand-held percussion machines In Vibro-Impact Dynamics of Ocean Systems Related Problems.
[3] Sokolov I J, Babitsky V I, Halliwell N A 2007 Hand-held percussion machines with low emission of hazardous vibration J. of Sound and Vibration 306 59–73.
[4] Nagaev R F 1985 Mechanical processes by repetitive collapsing collisions (Moscow: Nauka).
[5] Poderni R Iu, Chrpmoi M R, Sandalov V F 2003 J. of Mining machines and automatics 12 41–44.
[6] Verzhanskiy A P, Yungmeyster D A, Lavrenko S A 2014 Mechanized complexes for roadway development at mines of “metrostroy” (St. Petersburg: JSC).
[7] Ivashutenko A S, Martyushev N V, Vidayev I G, Kostikov K S 2014 Influence of technological factors on structure and properties of Alumina-Zirconia ceramics Advanced Mater. Res. 1040 845–849.
[8] Jungmeister D A, Krupenskiy I, Lavrenko S A 2018 Analysis of upgrade options rotary drilling with DTH J. of Mining instit. 231 321–325.
[9] Dashko R E, Alexandrova O Yu, Kotyukov P V, Shidlovskaya A V 2011 Features of engineering-geological conditions of St. Petersburg Urban development and geotechnical construction 1 1–47.
[10] Ivanov K I, Latyshev V A, Andreev V D 1987 Drilling techniques in the development of mineral deposits (Moscow: Nauka).
[11] Zverev E A, Skeeba V Yu, Martyushev N V, Skeeba P Yu 2017 Integrated quality ensuring technique of plasma wear resistant coatings Key Engin. Mater. 736 132–137.
[12] Skeeba V Yu, Ivancivsky V V, Martyushev N V 2016 Numerical simulation of temperature field in steel under action of electron beam heating Source Key Engin. Mater. 712 105–111.