Substantiation of the Draghead Application as a Mining Unit in Conditions of Solid Minerals Deep-Sea Mining

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Abstract. Deep sea solid mineral resources (SMR) of the World Ocean, such as ferromanganese nodules (FMN), cobalt-manganese crusts (CMC) and the depth polymetallic sulphides (DPS) should become an alternative source of mineral resources in the near future. Reliable and productive complexes are necessary for the implementation of deep-sea mining on an industrial scale, which will be able to develop deposit with a minimum ecosystem load. So, the main problems in technological solutions are the collection or separation of SMR at the bottom and lifting them to the surface. As a technical solution, it is proposed to use a special construction draghead device for FMN and CMC collecting and separating from the bottom. The distinctive feature of the device is a vertical axis of rotation of the drive engine and the working body, which can be represented by a faceplate or a crown, the working element with the engine are concentrically inscribed in the casing with the catcher, which enclose the loosening zone, protecting surrounding water area from the turbulent mud and separated fractions. Nodules and crusts lifting using the draghead is carried out in the form of slurry through a pipeline.

1. Introduction
Modern assumptions and prospects for the industry development of advanced countries inevitably lead to the need to increase the consumption of mineral resources. The depletion of exploited mineral deposits and the complication of mining and geological conditions for their extraction lead to the need to search for new areas of occurrence of mineral resources, including strategic ones. In the near future a resource base of deep-sea deposits of the World Ocean can become such a region [1].

Among the variety of the World Ocean mineral resources of considerable interest are solid mineral resources (SMR): ferromanganese nodules (FMN), cobalt-manganese crusts (CMC), the depth polymetallic sulphides (DPS) [2, 3]. It is known already that the ocean mineral reserves by the majority of indicators and the content of useful components [4] significantly exceed similar continental reserves and have a huge resource potential [3, 5, 6, 7].

Complex conditions of occurrence of crusts, nodules and sulphides (deposits are at great depths: FMN: 4200-5500m; CMC: 500-3500m; DPS: 850-4200m [3]) lead to the fact that production on an industrial scale is currently impossible.

2. Actuality
International seabed areas are regulated by the International Seabed Authority (ISA), which was established at the United Nations. At the moment, the Russian Federation has international contracts and obligations to the ISA. Contracts for a period of fifteen years have been concluded: since 2001 for
FMN; since 2012 for DPS; since 2015 for CMC [8]. To fulfill obligations under contracts and the possibility of their further extension, it is necessary to conduct exploration work, develop technical means of extraction and production technology, and conduct environmental studies and so on. Obligations for geological exploration are most effectively fulfilled, but significant problems arise in the conduct of research and development of technical means of production.

There are many domestic and foreign projects of mining complexes that allow mining of SMR from great depths, but they are represented only by experimental development that didn’t carry out industrial production. The real experience of carrying out mining operations for the DPS production of industrial scale can be realized in the near future by the company "Nautilus Minerals Inc" and their project Solwara 1 in the area of the Sea of New Guinea at a depth of 1800 m. [9, 10]. The project provides extraction of ore mass in the amount of 2 million tons per year. It is proposed to use 3 mining machines with remote control based on a tracked chassis for the preparation of the ore field, DPS crushing and gathering. Lifting of ore to the support vessel will be carried out in the form of slurry through a vertical pipeline with a displacement type pump. The ore will be loaded onto the barges and transported to the shore after the initial enrichment. [11]

In general, the process of deep-sea ores extraction can be divided into two main stages: the process of separating the ore from the bottom (which may include loosening, grinding or gathering); and the process of lifting the ore to the water surface. Justification of technological and technical solutions for the implementation of these polymetallic ores of FMN and CMC collection processes and their rise to the surface cause significant problems. [8]

There are theoretical developments for underwater SMR mining (including FMN and CMC mining) complex, which includes a surface boat (ore material collector), an intermediate capsule with atmospheric pressure [12] and pulp pumping equipment located in it, and near bottom mining machine with a dredge device [13]. Separation of the useful component in such complexes occurs mechanically, and transportation – hydraulically. The distinctive feature is that the slurry runs up to capsule because of the pressure difference due to the capsule submersion depth [14, 15], and further transport to the surface ore collector is carried out by dredge pumps (mud pumps). The working body of the dredge device can be represented, for example, by a ripper drum with a horizontal axis of rotation [13]; a truck [16] can be articulated with a device for trapping the FMN graded fractions (by a catcher).

The main disadvantage of this working body is the lack of 100% guarantee hit of nodules separated from the bottom into the catcher (the draghead efficiency factor) [17], which significantly reduces the real performance of the complex, exposure of SMR crushing zone and pollution of the mining water area. That is why there is a need to develop a draghead with a working body that has high performance and reliability as well as a low level of the water area pollution. At the same time, the conditions of occurrence and the geological conditions, as well as the requirements for the cutting force and feed for the FMN and CMC mining differ, the requirements for the working bodies are different, that is why there is a need to develop two working bodies: for the extraction of deep-sea nodules and for the extraction of deep-sea crusts.

3. Working body for FMN mining
To improve the efficiency of the considered draghead (increasing the draghead efficiency factor), as well as reduce the negative ecological effect on the environment, the catcher as an entrance to hydrotransport system was suggested to dispose above the FMN loosening zone. What is more, the axis of rotation of the working body and the drive motor (DM) is installed vertically, and the working body and DM are inscribed concentrically into the pipeline to form an annular through passage channel [18, 19] (fig 1).
The construction of the proposed draghead is as follows: the working body is a faceplate 7 with cutting plates (bits) 5 which is fixed in the horizontal plane directly (without further transmission) to the engine shaft 1. This predetermines the type of the engine as high-torque with a vertical axis of rotation. The driving torque from the engine to the faceplate is transmitted via a splined connection.

The faceplate has holes 4 for passing nodules and cutting plates 5 are fixed at average diameter \( D_{\text{average}} \). The engine 1 and casing 6 form an annular channel 2 with a minimum diameter \( D_{\text{HE}} \), a maximum diameter \( D_{\text{case}} \) and a cross section \( S = \frac{\pi}{4} \left( D_{\text{case}}^2 - D_{\text{HE}}^2 \right) \). A tapered catcher 3 is welded to the casing 6, covering with a technological gap (its cross section is minimal and must ensure that the faceplate 8 with the catcher 3 does not touch) the area of the faceplate with cutting plates.

The movement track of the loosened material passes only through the holes 4 in the faceplate 7 and then through the annular channel 2 [18] to the section of the lower pipeline 8. The sections of the pipeline are interconnected by spherical joints 9, which enable the sections rotation relative to each other by an angle not exceeding 15°. [20]

To increase the flyweight of the engine 1 and balance the rotating masses, the detail part 7 must be concentric to the shaft, which corresponds to the adopted shape of the part - "faceplate".

When operating (fig. 2), the tool is buried in the sludge by means of hydraulic cylinders (they aren’t shown on fig.1) to a depth not exceeding the height of the cutting plate \( B \), torque and angular velocity \( \omega \) is transmitted from the engine 2 to the faceplate 7. The oscillation of the working element in the horizontal plane with a certain speed \( V_{\text{beam}} \) is carried out by an incomplete rotating hydraulic...
motor rigidly connected with the draghead by means of a boom, the length of which corresponds to \( R_{\text{beam}} \), and the angle of rotation corresponds to \( \varphi \).

After reaching the extreme point, the self-propelled truck with draghead moves to a distance \( h_{\text{DV}} \) with the speed \( V_{\text{DV}} \), and the process of swinging the working body is repeated in the opposite direction. The turbulent mud with the nodules get through the holes 4 in the faceplate 7 and through the annular channel 2 - into the lower section of the pipeline 8 and then to the intermediate capsule, from which the slurry is pumped to the ore collector by dredge pumps [21].

4. Working body for FMN and CMC mining

The technical solution, proposed earlier, will be suitable for both the FMN mining and for the extraction of CMC; the difference will be directly in the working body. It is possible to use a draghead with a working body represented by a conical cutting head for the extraction of cobalt-manganese crusts (CMC) (fig. 3) [21, 22]. Taking into account that crustal formations in their strength properties are similar to coal [23], we can assume that the production process by the conical head will be identical for crusts and coal. It is worth noting that the draghead with a conical head is also suitable for nodules mining, but the production efficiency will be lower.

Figure 3. Draghead with crown executive body;
1 – catcher, 2 – engine of working body, 3 – shaft, 4 – conical head, 5 – casing, 6 – holes, 7 – annular channel, 8 – vertical swing hydraulic cylinder, 9 – boom, 10 – rotary hydraulic cylinder, 11 – truck, 12 – spherical joint, 13 – pipeline, \( D_{\text{crown}} \) – conical cutting head diameter, \( D_{\text{SC}} \) – catcher diameter, \( l_0 \) – holes in the head, \( D_{\text{HE}} \) – outer diameter of a hydraulic motor body, \( D_{\text{case}} \) – inner diameter of the catcher casing

Figure 4. Draghead with cutting head operating scheme;
\( R_{\text{beam}} \) – boom length on which draghead is fixed, \( \varphi \) – boom sweep angle, \( V_{\text{beam}} \) – draghead feed rate (boom sweep rate), \( V_{\text{DV}} \) – moving speed of a self-propelled truck, \( h_{\text{DV}} \) – movement step of a self-propelled truck, \( B \) – head penetration depth, \( D, d, h \) – head design parameters

Conical cutting head 4 is fixed to the shaft 3 of the engine 2. There are holes 6 in the head with linear dimension \( l_0 \) for passing crushed rock masses. The engine 2 and the casing 5 form an annular
channel 7 with a minimum diameter $D_{HE}$, a maximum diameter $D_{case}$ and a cross section $S = \frac{\pi}{4} \left( D_{case}^2 - D_{HE}^2 \right)$. A tapered catcher 1 is fixed to the casing 5 with a maximum diameter $D_{SC}$, covering the nodules or crusts loosening area with cutting head. The loosened rock masses get into the annular channel 7 both through the gap between the catcher and the head and through the holes 6 in the head 4. The condition $l_0 \geq d_n$ (dimensions of FMN nodules don’t exceed $d_n \leq 100$ mm) must be fulfilled for nodules to get into the annular channel of the draghead when mining FMN. The total area of the holes through which the separated nodules pass over should not differ from the area of annular section $S$. Whereas, the area of the annular channel must not differ from the area of the lower pipeline, this will lead to a more efficient process of hydraulic lifting with minimal energy losses along the pipeline route and the absence of solid precipitation on the condition of the critical velocity exceeding $21$.

To carry out the extraction, the working body is drilled into the formation at a certain depth $B$. The splined connection on the shaft 3 of the drive engine 2 transfers rotation to the working body, the movement in the vertical plane is carried out by one swing hydraulic cylinder 11. In the continuous cutting process, the displacement of the working element (fig.4) in the horizontal plane is made along the arc of the boom 9 with the radius $R_{beam}$ by the rotary hydraulic cylinder 10 with the speed $V_{beam}$ by the prescribed angle $\varphi$ and the movement of the self-propelled truck 11 with the speed $V_{DV}$ forward (backward) by a distance $h_{DV}$.

5. Conclusions

It is proposed a construction of a draghead with a vertical axis of rotation and a catcher covering the loosening area, which allows reducing losses of a mineral at extraction and providing a given productivity of underwater mining complex, i.e. to increase the efficiency of the draghead to almost one. $[17]$

The development zone for this draghead operation is completely covered by a catcher, in which the draft is created, thus, all the turbulent muds entirely will fall into the flow path of the draghead, which leads to a reduction in the water area pollution.

The working bodies are offered: a faceplate of a special design for the FMN mining; conical cutting head for the CMC and FMN mining. The application of these working bodies will lead to the efficiency increase of deep-water SMR extraction.

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