Design of Deep Seabed Mining System

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Abstract This paper reviews the past development of deep seabed mining system for manganese nodules, and aims at making a master design that will most probably be used in the first commercial nodule mining in the future. We discuss about the design of four subsystems and think the best mining system up to now that should be an assemble of specially designed vessel, hydraulic lifting pipe, self-propelled hybrid miner and integrate-separate control system. To shorten the research period and reduce risks, we can make use of the well-developed techniques and international co-operation. It also introduces Chinese deep seabed mining research projects.

Keywords deep seabed mining system, lifting pipe, surface vessel, miner, master design

1 Past developments

Several technologies for deep sea-bed mining have been developed and tested on pilot project scales. Previous experiences in deep water, oil and gas exploration were in water depths of 300～500 m, far less than the 5 to 6 km depth involved in deep seabed mining. The deepest sea-bed depth from which dredging had been carried out was 1 000 m, still far below the mining depths. OTEC(the Ocean Temperature Exchange Circuit) plants involve depths in the order of 1 000 to 2 000 m, which is still a developing technology. Yet, understanding of design for great depths in hostile environment provided by technologists has been proved useful for mining.

Probably the earliest technology developed and tested in a pilot scale is the Continuous Line Bucket (CLB) system which has either one or two (Fig. 1)[1] ship version. The earliest effort by

(a) one ship (b) two ship

Fig.1 Continuous Line Bucket(CLB) system

收稿日期: 1999-04-26

Japanese was in Hawaii in 1972 and off Ogasawara islands in 1975 in a water depth of 4 000 m. Later, French AFERNOD also pursued after this system. The CLB system did not win favor on further development due to several reasons, principally low recovery rates and efficiency, serious disturbance to the sea bed sediment layer and thorough sediment mixing in the entire water column, and liable to entangled.

The first test with a system, which was a precursor to what is widely held acceptable today(Fig. 2)[1], was done by OMI (Ocean Management Incorported) in 1978 in the Pacific using a refitted drill ship and a towed collector vehicle in water depth of 5 500 m. Two pick-up systems (on the collector) were tested, one hydraulic and the other mechanical type. Also tested were two types of lift systems, the air lift system and the hydraulic (using multistage mixed flow pumps) lift system. The achieved recovery rate was 30 t / h. In the same year, OMA(Ocean Mining Association) and OMCO(Ocean Minerals Corporation) carried out pilot system tests using a similar system, but adopting a hydraulic pick-up and air lift transportation. The OMCO test used a collector driven by Archimedean screws. In 1979, mining of metalliferous mud was undertaken in Red Sea from a water depth of 2 200 m by Preussag (Germany) using a drill ship. The mud was picked up by a suction head at the lower end of the pipe string driven by an onboard pumping station. Japan also actively engaged in developing both pneumatic and hydraulic mining system for pilot testing in late 1990 s (up to now it is not reported). There is also evidence that the CLB system is under a new lease of development.

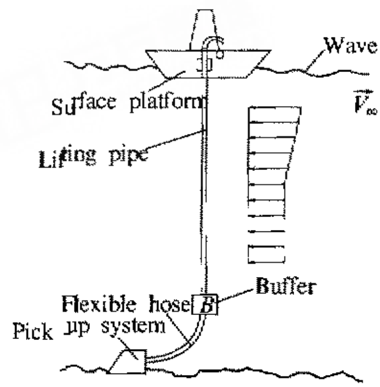

Fig.2 Deep sea bed mining system

2 Master Design of Deep Sea Mining System

Generally speaking, a deep seabed mining system for manganese nodules consists of lifting system, surface vessel, control system and miner. Fig. 3 shows the mining system developed in China that will most probably be used in the first commercial module mining in the future[2]. The hydraulic lifting mining system people generally recognize is the most practical system up to now, manganese nodules mined by the collector on the seabed are hoisted to the surface vessel with hydraulic raising dynamics through a vertical lifting pipe string, and it deploys a maneuvered self-propelled collector. It has the following charactristics; ① better mobility; ② high pick up rate; ③ ability of avoiding obstacles and disadvantageous topography on the seabed; ④ big exploiting scale; ⑤ less difficulty in technology.

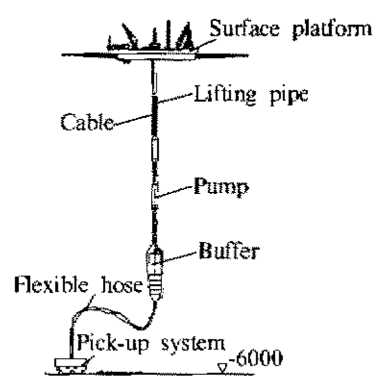

Fig.3 The deep sea bed mining system developed in China

As mentioned, this system consists of a surface ship from which the pipe-string is suspended to lower the miner onto the sea-bed. A buffer station is located at the end of the pipe string and connected to the miner by a long, flexible hose so that the miner can have a desired radius of operation when the surface platform is stationary[3]. This long flexible link is fitted with buoyancy modules so that it does not sink to the seafloor. This avoids its coming in way of the miner and getting entangled. The tube through which the nodule-sediment-water mixture flows after being picked-up has a meshed portion. The sediment under high flow rate is partially discharged through this mesh, thus facilitating their quick resettlement. The mixture then passes through a crusher which breaks down the nodules to manageable size so that the nodule-water-sediment slurry can be transported up. The nodule sizes are usually too big compared to the pipe-string diameter, thus require crushing procedure. Furthermore, the pick-up rate and the lift rate may have a mismatch, and to avoid the situation the former is larger than the latter, a buffer station is provided as described above serving as a temporary storage of the slurry. The buffer station also performs an additional function, namely, providing ballast to the lower end of the pipe-string to partially neutralize its large buoyancy. This helps to keep the long pipe-string nearly vertical, especially when there is a strong current. The miner has a row of nozzles which impinges high velocity jets on the sea bed dislodging the nodules from it. In the process, the top sediment layer is also disturbed. The nodules float just off the bed in the sediment cloud and either picked up by a hydraulic pump (hydraulic system) at the well designed mouth or by a conveyor mechanism (hybrid system). The lift system consists of several (i.e. multistage) hydraulic pumps fitted at intermediate locations within the pipe string. The diameter of the pipe string are small, so are the pump diameters, hence several pumps are required. The power supply to the collector and the hydraulic pumps housed in the pipe-string is through a power cable bundled together with the pipe string with separate onboard winch for its storage and deployment.

After describing a possible selection of the mining system, it may be of help to crystallize the concepts with the aid of some available numerical data, even though incomplete in many respects. KSB in German has designed and tested a hydraulic lift system for a 5 250 m water depth site[4]. The system carries up to 60 mm size nodules (after crushing) in a slurry with 5 % volume of solids. The capacity of delivery is 500 m^3/h including solids, i.e. 25 m^3/h of solids. This means 50 t / h rate of transport of nodules assuming the nodule specific gravity is 2. The system has two submersible motor pumps in series closely beneath one another at a depth of approximately 1 000 m, each designed for a water head of 265 m. With assumed slurry specific gravity of 1.1, each pump develops a discharge of 30 atmospheres. The discharge pressure immediately downstream of the second pump is therefore 6 MPa. The rating of each pump is 800 kW, speed 1 726 r which draws a current of 158 A at 4 000 V. The design considerations of the pumps were ① minimum flow velocity of 2.5 m / s, higher than the sinking velocity of nodules, ② flow passage of 75 mm to provide unobstructed passage of nodules and ③ material coming in contact with slurry should withstand corrosion and erosion by the nodules.

3 design of the subsystem

3.1 Surface Vessel

Attention will be devoted now to the functional requirements of the surface vessel. Though it is possible to conduct a pilot scale mining test using an existing ship refitted for the purpose, a commercial mining platform must be specifically built for long term mining. The platform must support the storage and deployment of the enormously long pipe-string, the power plant, the slurry cleaning system, the discharge system, the storage and deployment of the power and communication cables, the control and UW communication equipment and, if desired, preliminary processing of the nodules. It must also be able to receive men, material, spares and fuel from other vessels effectively and transport semi-processed nodules to an ore carrier for transporting them to shore. The platform must have station keeping devices (active thrusters) to resist drift and active or passive anti-roll devices to offer a stable platform for mining. This is because a platform with excessive wave or wind induced motion and/or drift will lead to suspension of mining activity, thus downgrading productivity. Therefore dynamic positioning has to be used. Such a range of tasks can be done in a cost-effective way only by a mission specific design[5].

3.2 Lifting Pipe System

In deep seabed mining represented by production of manganese nodules out of 5 000～6 000 m sea water depth, a vertical lifting pipe is the largest part of the production line connecting surface platform with a miner on the seabed via underwater pumping unit. A pipe string transporting the manganese nodules supports various cables at the outside and carries pump modules and buffer during mining operation.

In the hydraulic lift system, the nodule slurry is lifted up by hydraulic pumps housed inside the pipe-string at intervals, whereas in the air lift system it is sucked up through the pipe by injecting compressed air into the pipe-string[6]. The experience on the air lift and hydraulic lift systems shows that the former requires much larger power than the latter. The current choice is therefore the hydraulic lift system.

As a rule the inner diameter is selected for optimal lifting efficiency, and the outer diameter is designed to withstand the static due to its weight in water and the dynamic loads induced by the motions of surface platform and external flows in waves and current.

The pipe-string is subjected to wave and current induced forces in its upper 150 m length. Its huge length (5 to 6 km) renders it extremely flexible to bending deformation, hence the qualifier' string'. It can therefore take a curved shape under strong current. The buffer station helps reduce the curvature of the pipe-string by suitable ballast. For the 5 000～6 000 m pipe to transport manganese nodules vertically from the seafloor, dynamic pipe streching oscillation would occur, being initiated by vertical components of the platform or ship motion, or coupled with internal flow interaction with the axial oscillation of the pipe[7]. The large oscillatory pipe stretching comes from the resonance, can significantly influence the design and operation. This dynamic amplification depends upon the wave climate and can cause severe damage or even failure (including fatigue failure in the long term), which must be prevented by design, for example: ①use of dampers and thrusters, ②altering the pipe wall thickness, length and weight. ③use of the heave compensators onboard the ship and along the pipe[7], ④use of suitable cables formation outside the pipe to repress dynamic stretching[8]. Furthermore the lower part of the pipe-string is subject to very high pressures and low temperatures. Added to that is the corrosion by seawater outside and corrosion and erosion by nodule slurry flow inside. The selection of material becomes extremely important due to these factors and development of new material will improve its performance.

Another critical point to be considered is the extricating installation to avoid heavy storm.

When the mining operation zones are hit by typhoon or tropical storm the vessel must be separated from underwater systems and navigate to safe region, but UW(underwater) systems still remain on the mining zones. After storm, vessel returns to the original site and is reconnected with underwater systems.

3.3 Miner (Collector)

The Miner for deep sea mining travelling on the seabed, collecting the manganese nodules and transporting the nodules to the lifting system is one of the most critical parts in mining system. Miner designing depends on operating conditions and functions. There are high pressure, corrosion and very soft sediment with varying properties on deep sea bed. The three important factors, that is module grade, abundance and terrain characteristics, determine the value and economics of a mine site, causing that miner design principles different from the vehicle on land. In addition, environment protection should be considered in miner design.

The miner, which consists of pick-up device and vehicle, should have high reliability because it is operated at the deep seabed under 5 000～6 000m. Its pick-up efficiency has an important effect on the total efficiency of the whole mining system[1].

Between the hydraulic and mechanical miner, the hydraulic one is usually preferred due to its favourable power consumption and 'cleaner' pick-up features, but a hybrid (hydraulic-cum-mechanical) model is believed to be a superior choice[9]. Many hybrid collector configurations have been developed and tested in laboratory (Fig. 3). The movement of the collector on the sea-bed favours the choice of a crawler type vehicle rather than the Archimedean screw. The caterpillar tread is composed of rubber with high involved grousers. Advantages of this caterpillar tread are simplicity, less weight, and good self clean. During mining operation the grouser would be high enough to dig into sediment to provide sufficient traction. Since thixotropy to the layer of sediments, disturbance to the sediments should be minimized. So the involved grouser is one of the best choices up to now.

The miner can either be towed by the surface platform or be self-propelled when it can do mining over a certain radius around the stationary location of the platform. A self-propelled collector has to be remotely controlled (i.e. maneuvered and propelled) by UW communication links from the surface platform and will require additional power. Despite larger sophistication involved in these data links as well as the power consumption requirement, the self-propelled collector is obviously preferred over a simple towed one because the latter cannot mine all nodules from a given area leaving patches and strips untouched and therefore wasteful(In the mining operations a miner on the seafloor moves along prescribed mining tracks from north to south or from south to north, as will be designed by combination of straight courses, curves, U-turns and so on depending on the mining sites.)[8].

3.4 Control system

A reliable and sophisticated UW control and communication system is very important. The control system is integrated with many kinds of information, which are independent on and correlative to each other. The operation process of every sub-system must be shown in one picture so that the operator can monitor the condition of the whole mining system at the same time. Controlling of every sub-system is independent, but with some relations. Therefore the control system must adopt an integrate-separate control model. Compared with others, three dimensional dynamic behaviors of mining system is the best one. 3-D analysis of lifting pipe is of basic requirement for developing of a total integrated positioning system controlling automatically the path, speed and heading of mining ship in tow maneuver as well as for design of optimal mining track. UW communication is a less developed area and requires high reliability for continuous operation[8].

4 Deep sea bed mining in China

China began its national project of manganese nodules exploration and exploitation comprehensively in 1990, afterwards registered as pioneer investor at Sea Bed Authority of UN in 1991[10]. China has extensively surveyed around this area for near ten years, in May 5th 1999 China locked 7.5 million km^2 in east Pacific Ocean. China Ocean Mineral Resources Association(COMRA), which was set up in 1991, holds leading position in administration of national project, and makes a lot of research achievements. Fig. 3 is the deep sea bed mining system under development in China.

During " Eighth five-year Plan" COMRA put a large portion of its research fund into the exploration of manganese nodule resources in Chinese pioneer investor area. Mining technology of manganese nodules was in the scale of laboratory testing.

The Ninth Five-Year Plan from 1996—2000 is in process, research activities concentrate in special technology of collecting and lifting, such as: high efficient miner, to reduce power consumption with high pick up rate, to minimize the disturbance to sea bottom based on COMRA miner and existed miners, to design and test a sea bed tractor with high traction and moving on extremely soft soil properly based on crawler, parameter study of hydraulic lifting, to deal with flexible hose transportation, integration of measuring and controlling system, and to study the environmental consequences, including the influences in sea bottom by mining and Natural Variability of Baseline study.

China welcome cooperation in followings to invest together and plan pilot mining test; to work on research and development of surface vessel; to research key technique, that is technique in deep sea mining, e.g. Trace keeping of the miner.

5 Conclusions

Because of huge investment for deep-sea mining, long research period, and many discipline concerned, we must concentrate our research and development on the integration of technologies. That means to accept experiences from other fields and new achievements to reduce risk, such as offshore petroleum production already well developed up to date, of which some devices and techniques can be used in deep seabed mining. As far as sea bed environment concern, engineers in deep sea mining should work closely with environmental scientist to pay more attention to see bottom problem. Moreover, we can go into international co-operation to give each other full play to advantages.

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深海采矿系统设计

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摘 要 通过对深海多金属结核采矿系统发展的回顾，提出未来商业开采系统的总体设计思想，并详细介绍了4个子系统的设计，认为目前最具有发展前途的采矿系统应由一艘特殊设计的采矿船、水力提升扬矿管、自行复合式集矿机及集散控制系统组成。指出为减少研究周期和降低风险，既要充分利用已成熟的技术成果，又要加强国际合作。最后介绍了中国深海采矿的研究情况。

关键词 深海采矿系统，扬矿管，还面采矿船，集矿机，主体设计

分类号 TD 424