Research status and Thinking on vibration reduction of mining pipe in deep sea mining

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Abstract

This paper mainly studies the research process of deep-sea mining at home and abroad, summarizes the research status and development trends of vibration reduction of lifting pipe in deep-sea mining at home and abroad, and puts forward some views on vibration reduction of lifting pipe in future deep-sea mining, that is, to install distributed dynamic vibration absorber on the lifting pipe, and finally how to speed up the process. Opinions on the development of deep-sea mining in China are put forward.

Keywords

Deep sea mining, lifting pipe, vibration reduction, research status at home and abroad.

1. Preamble

With the rapid development of the global economy and science and technology, the earth's terrestrial mineral resources are increasingly tense, the national defense of the world, especially the struggle for maritime rights and interests continues to strengthen, countries are vigorously developing marine science and technology, active exploration and mining of mineral resources, especially rare metals, so the global focus will be concentrated on the rich reserves. The polar regions and oceans rich in metal resources, including deep-sea mineral resources such as polymetallic nodules, polymetallic sulphides and cobalt-rich crusts, are the source of various mineral resources needed for human development activities.

According to a research report by Professor Merlot of the University of California, the world's oceans have polymetallic reserves of about 2-3 trillion tons, and the Pacific alone has 1.7 trillion tons. Deep-sea nodules of polymetallic minerals, also known as manganese nodules, generally 0.5-20 cm in diameter, are widely distributed in the 4000-6000 m deep seabed, containing more than 70 elements, such as copper, drilling, nickel, manganese, iron, tungsten, Qin, aluminum, gold, silver, platinum, etc. The average grade of nickel, drilling, copper and manganese is 1.3%, 0.22%, copper 1%, and manganese 25%. Manganese reserves in the Pacific Ocean are estimated to be 200 billion tons, 57 times that of land, 83 times that of nickel, 9 times that of copper and 539 times that of drilling. Deep-sea polymetallic nodules are mineral resources that can be utilized by human beings in the future. The gradual depletion of mineral reserves on land is an important motive for marine mining research.

2. Development of Deep-Sea Mining at Home and Abroad

Since the 1960s, some western developed countries and international consortia have invested heavily in the exploration, mining and beneficiation of deep-sea polymetallic nodule deposits. Four international consortiums (OMI, OMA, KCON, OMCO) are composed of the United States, Canada, Belgium, Italy, Germany, the United Kingdom, Japan and the Netherlands and other Western countries. A large number of studies and experiments have been carried out on the marine polymetallic nodule mining system. The United States, Japan, Germany, France, Canada, Russia, Norway, India and South

Korea have set up national-level marine mining research institutes, which regard the possession and development of international seabed resources as an important part of the National Marine strategy, and have formed a variety of mining systems and conducted several marine experiments.

In 1990 4, the State Council approved the "China Ocean Mineral Resources Research and Development Association". To organize and coordinate China's research and development activities in the international seabed areas, safeguard the rights and interests of the state in developing international seabed resources, and apply to the UN Seabed Management Preparatory Committee for registration of mining areas. In March 1993, China was registered as a pioneer in the development of the international seabed by the International Seabed Authority and the Preparatory Committee for the International Tribunal for the Law of the Sea, and allocated 150,000 square kilometres of the international seabed area. On March 5, 1999, after discharging the obligation in 50% of the open-up areas, China acquired 75,000 square kilometers of nodule mining areas with exclusive exploration rights and preferential commercial exploitation rights in the above-mentioned areas, safeguarding China's rights and interests in the "blue enclosure" movement.

The study of oceanic polymetallic nodule mining system in China began in the 1980s. After more than 30 years'efforts, great achievements have been made. Especially since 1990, the China Ocean Association has organized and concentrated the technological research superiority of domestic mining engineering and marine engineering, and initiated the exploration and development technology of oceanic polymetallic structure mineral resources. A special national study sponsored research institutes and institutions in China to start research and experimental work on mining technology of oceanic polymetallic nodules. After thoroughly understanding and analyzing the development history and present situation of deep-sea mining technology in Japan, the United States and Germany, the deep-sea polymetallic nodule mining scheme based on mining vessel, fluid pipeline transportation and self-propelled collector in China is determined.

3. Research Status and Development Trend of Longitudinal Vibration Damping for Deep-Sea Mining at Home and Abroad

The deep-sea polymetallic nodule mining system is subjected to tremendous loads in complex marine environments, in which the surface support system is subjected to sway, sway, heave, pitch, roll and yaw motions and their coupled motions, which have a significant impact on the reliability of the underwater lifting system and the seabed mining system attached to the surface support platform. Especially, the heave motion caused by ocean wave motion has a significant impact on the safety and stability of deep-sea mining system.

Longitudinal deformation and maximum axial stress are the main basis for the design of fatigue strength of the lifting pipe. The longitudinal deformation and maximum axial stress of the lifting pipe must be reduced as much as possible. The axial stress and deformation of the lifting pipe are mainly caused by the longitudinal vibration of the lifting pipe. The lifting motion of the mining ship, a subsystem of the sea surface support system, is easy to induce the vertical vibration of the lifting pipe suspended vertically on it. Longitudinal vibration of the lifting pipe is the most dangerous movement for the lifting pipe itself and deep-sea mining operations. Corresponding measures must be taken to reduce or even eliminate the vertical vibration of the lifting pipe as far as possible.

The research team headed by Professor Chung J S of the United States began to systematically study the lifting subsystem of the deep-sea mining system since 1980. In 1982, the related motion characteristics of the lifting pipe and the longitudinal vibration of the lifting pipe were studied. The dynamic equation of the whole lifting pipe was established by the finite element method, and the ship was built. The ship and buffer cabin are the boundary conditions of the equation. In 1994 Chung, Cheng and Huttelmaier studied the three-dimensional nonlinear "bending-axial-torsion" coupling response of a hard pipe with constant diameter under the combined action of buoyancy, wave force and ocean current.

Japanese scholars have done a lot of research on the longitudinal motion law of the hard pipe. The weight of the pipe is assumed to be a mass-less spring, ignoring the weight of the pipe itself, and the pump assembly and buffer are regarded as the concentrated mass. At the same time, there are vibration absorbers at the lower end of the pump group and buffer. The analysis is carried out according to the four degrees of freedom. The free longitudinal vibration and the steady longitudinal vibration of a two-step lifting pipe with a buffer at the lower end and a mining ship moving up and down are analyzed. The natural frequencies, natural modes and amplitudes of the free vibration of the lifting pipe are obtained, and the parameters are considered on the basis of the analysis. Excited vibration.

Hong Xie of South Korea pointed out that the period of the first-order axial natural vibration is in the range of high wave energy and the dynamic stress of the axial vibration is one of the most important factors in the design of the hard pipe for mine lifting. A lumped mass method for time domain analysis of the hard pipe for mine lifting was proposed. The axial and transverse vibration of a model of hard pipe for mine lifting with pumps and buffers was studied. The influence of towing characteristics is analyzed, and the nonlinear dynamic analysis of three-dimensional towing characteristics is carried out.

Up to now, there are three main methods to reduce or even eliminate the longitudinal vibration of the lifting subsystem, especially to prevent the resonance between the lifting subsystem and the sea wave, and to minimize the longitudinal deformation and axial stress of the lifting subsystem.

(1) Improving the structure of the mining subsystem.

Kazuo Aso of Japan and others studied the drag coefficient and additional mass coefficient of different cabin configurations. His student Cui Gang pointed out through the study that the use of the stepped and segmented lifting hard pipe model can effectively reduce the maximum axial force, so that the axial tensile stress along the hard pipe is reasonable and the cross-sectional area is large. The maximum axial stress can be reduced by more than 25% compared to the small homogeneous pipe. The results of Kazuo Aso and other studies also show that the hydrodynamic forces acting on the middle cabin at the bottom of the lifting subsystem have a great influence on the dynamic characteristics of the whole lifting subsystem, that is, when the towing force on the middle cabin is relatively large, the overall longitudinal amplitude and axial stress of the lifting subsystem are relatively small, so the structure of the lifting subsystem is very small. It is also pointed out that the shafting shoulders of the middle cabin should be designed to maximize the cross-sectional area perpendicular to the longitudinal direction of vibration as far as possible so as to reduce the maximum amplitude of resonance; and the outer diameter of the shaft shoulder of the middle cabin should be further designed later. Parameter optimization is carried out with shaft shoulder spacing. Kazuo Aso and Chung.J.S. both studied the method of using elastic joints to reduce the axial stress of the lifting subsystem, and compared the damping effect of elastic joints between the lifting subsystem and the three joints of the mining ship, pump and cabin. Chung and Cheng also use flexible joints to change the natural frequency and bending moment of the lifting subsystem. Finite element method and mass spring element method are used to analyze the static and dynamic characteristics of the lifting subsystem. It is pointed out that the rigidity and installation position of the flexible joints have great influence on the effect of lowering the maximum bending moment of the lifting subsystem. The natural frequency of the variable lift subsystem can effectively reduce its maximum longitudinal amplitude, but the effect of reducing axial stress is not obvious.

(2) Passive control methods such as additional vibration absorbers.

Kazuo Aso also uses an additional vibration absorber to reduce the dynamic maximum axial tensile stress by changing the natural frequency of the lifting subsystem itself to prevent resonance. It is pointed out that nonlinear spring is more effective than linear spring in vibration absorber design, and the change of spring stiffness is better to track the change of external vibration excitation frequency resistance, and the damping effect will be the best. In 1997 Chung and Cheng et al. further analyzed the static and dynamic responses of the mine lifting subsystem with axial vibration absorber and flexible joint, and reduced the axial stress caused by the longitudinal vibration of the pipe by arranging axial vibration absorber on the mine lifting riser.

(3) Semi-active control or active control is realized by means of vibration isolation, such as heave compensation system.

The method is to design and install a heave compensation device system between the lifting subsystem and the mining vessel, which connects the lifting subsystem with the mining vessel. Under the action of the lifting compensator system, the lifting subsystem can be kept as still as possible without the influence of the lifting motion of the mining vessel by means of the semi-active or active control strategy. The working principle of the lifting compensator system is that the excitation source of the longitudinal vibration of the lifting subsystem is eliminated fundamentally and the longitudinal vibration of the lifting subsystem is reduced. The longitudinal vibration of the lifting subsystem is reduced or even eliminated, and the ultimate goal of reducing the longitudinal deformation and axial stress of the lifting subsystem is achieved. Huang Kai, Guo Shengmin and Zhang Zhen of Central South University discussed the control method of heave compensation system for 1000m deep-sea mining system, and carried out simulation analysis based on ADAMS and MATLAB. Ni Jia studied the modeling of passive heave compensation system in deep-sea mining system, and carried out simulation analysis. Xiao Tibing and others of Guangdong University of Technology have studied the design of passive heave compensation system based on hydraulic cylinder motion. They have studied and designed passive heave compensation system under light load, medium load and heavy load, and have obtained some useful conclusions.

In order to achieve the best vibration suppression effect and minimize the longitudinal deformation and axial stress of the lifting subsystem, the above three methods can be used simultaneously. Some studies show that the maximum longitudinal amplitude of resonance in the middle cabin of the lifting subsystem can be reduced by 55% and the maximum axial stress of the lifting subsystem can be reduced by 42% by using the optimized lifting subsystem and vibration absorber.

4. Thinking

The distributed mass vibration absorber system is used to reduce vibration. The discrete distributed dynamic absorber, which conforms to the tuning frequency of a specific nonlinear interval in a small range, can not only better adapt to the space constraints, but also have wider damping frequency band and more stable vibration suppression effect. The vibration reduction effect under mistuning condition is also better than that of a single dynamic absorber. However, there is still a lack of research on the distributed vibration absorber.

In order to improve the safety and stability of deep-sea mining system, and to obtain better vibration suppression effect, adapt to the limitation of installation space, and improve the frequency band of vibration absorption, we should learn from ship vibration reduction method and adopt distributed mass vibration absorber to reduce the longitudinal vibration of lifting pipe. The amplitude and axial stress of vibration, and the optimal design of distributed mass damper parameters are also presented.

5. Prospects

Deep-sea mining is a new field of marine resources development, and the development of deep-sea mining technology is a national demand. After 25 years of hard work and wisdom, three generations of researchers have basically completed the system construction and major equipment development of deep-sea polymetallic nodule mining technology. However, to achieve the goal of commercial development of technology reserves, China has only completed the basic stage of the work, compared with the advanced countries have the technology reserves, is still in a backward state. At present, we should seize the favorable opportunity of uncertain commercial exploitation of deep-sea mineral resources, actively carry out work, strive to achieve commercial exploitation with developed countries at the same time, safeguard China's regional rights and interests with comprehensive strength, play a role in international affairs, and strive to achieve the goal of marine power.

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