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Application of Electromagnetic Emission Technology in In-Situ Subsea Dynamic Penetration Test

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Abstract. Subsea in-situ dynamic penetration test (DPT) is the latest equipment to directly acquire geological characteristics of a certain location on the seafloor. In this paper, electromagnetic emission technology is firstly applied to in-situ dynamic penetration test on the seafloor, so that the speed of the electric drive-out chamber can be changed without mechanical structure switching, thus the impact energy can be changed, thus switching between different types of dynamic penetration tests can be completed. This paper preliminarily completes the design of the whole machine for in-situ dynamic penetration tests of the seabed and designs an 8-stage accelerated impact head for this purpose. Combining with impact dynamics, the corresponding bore velocity is calculated. The 8-stage acceleration has experimented with equal ratio reduction. At present, the design of single-stage acceleration has been completed and the acceleration function of the small-mass electric drive has been obtained. Subsequent work includes eight cascade tuning and single-stage accelerate enhancements are moving forward steadily.

Keywords: Electromagnetic emission · Dynamic penetration test · Adjustable

1 Introduction

1.1 Marine Geological Exploration

China's strategy of going to the ocean and exploring the ocean is being gradually implemented. In this process, China has made a series of major phased achievements at the three levels of "ocean entry", "ocean exploration" and "ocean development". Among them, the current achievements in "ocean development" mainly focus on the development of marine resources, while the construction of marine engineering is still in the initial exploration stage.

The continuous development of marine engineering construction has put forward higher requirements for geotechnical engineering investigation. Conventional marine

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geotechnical investigation technology cannot meet the economic, fast and convenient development needs of geological exploration for such projects as cross-sea bridge, offshore oil platforms, sea wind pile foundation, marine pipeline and so on [1–5].

The contents of the marine geological survey mainly include submarine topography and geomorphy, submarine sediment, the shallow geological structure of submarine, evaluation of submarine mineral resources, etc. With the rapid development of marine engineering in recent years, the importance of studying the physical and mechanical properties of submarine strata has gradually become obvious.

There are various methods of marine geological survey, including drilling sampling, multi-beam, and other geophysical methods. Because in-situ testing is carried out in the original position of rock and soil, the measured soil body will not be disturbed before testing and maintains its natural structure, water content, and original stress state. The measured data are more accurate and reliable. Compared with the laboratory test results, it is more in line with the actual conditions of the rock and soil mass.

1.2 Dynamic Penetration Test

The structure of marine electromagnetic in-situ sounder is complicated. Considering underwater operation, some accessories on land need to be modified or disassembled to be suitable for operation under the sea. The power head and lever changing mechanism, together with key auxiliary components such as main support frame, main support, and hydraulic cylinder, and other components such as battery compartment, electronically controlled compartment, valve box, tank, track, and so on, constitute the marine in-situ touch detection test equipment [6].

1. The in-situ dynamic penetration test equipment of the ocean is hoisted to the target sea area by a marine crane so that the penetration test equipment is vertical to the seafloor. The maximum deviation of the verticality shall not exceed 2%. The penetration test rod shall be straight and firmly connected.
2. During penetration, the electromagnetic hammer system is activated to adjust the impact energy to the same level as light or heavy dynamic penetration test, and the height of the penetration test rod on the ground should not be too high to avoid too much tilt and swing.
3. Hammering rate should be 15–30 hits per minute. The penetration process should be as continuous as possible and all discontinuities exceeding 5 min should be noted in the records.
4. Timely record the number of hammers required per penetration of 0.1 m. The method consists of a built-in displacement sensor in a touch probe and a direct (or instrumental) record of the number of hammers hit. It is also possible to record the penetration of each shot, which is then converted to the number of hammers required per penetration of 0.1 m. Readings may not be recorded for the first 1 m of penetration.
5. For general sand, gravel and pebble, the penetration test depth should not exceed 12 m. Above this depth, the influence of the side wall friction of the penetration test rod must be considered.
6. Stop the test when the number of sleeping strokes required to penetrate 0.1 m exceeds 50 strokes three times in succession.

1.3 Electromagnetic Emission Technology

Electromagnetic gun is a weapon that generates electromagnetic force through electric current to push the shell forward. It converts the electric energy of the power supply into the kinetic energy of the shell through the launcher. At present, there are many forms of electromagnetic guns. Generally speaking, electromagnetic guns are divided into three categories: rail gun, coil gun and reconnection gun [7–11].

Sandia National Laboratory (SNL) of the United States took the lead in studying synchronous induction coil launch technology earlier than other research units. It has made a series of achievements in the experimental research of multistage synchronous induction coil launcher, and its research achievements have always been in a leading position in the world. So far, the United States, Germany, France, Britain, Russia, Australia, Iran, etc. have studied electromagnetic railguns, including the Institute for advanced technology (IAT) in the United States, the French German Research Institute of Saint Louis in France and Germany(ISL), and the Naval Research Laboratory (NRL),they are the world's most well-known scientific research institutions of electromagnetic orbit launchers.

China started late as a whole, but a large number of scholars and research units have gradually done some ideological and theoretical and practical exploration and research, followed up and achieved good results. Outstanding scholars represented by professors Weiming Ma, Ying Wang and Zhi Wang took the lead in advocating and promoting the research of electromagnetic emission technology, which promoted the development of synchronous induction coil launch technology in China (Fig. 1).

2 Research Method

2.1 Equivalent Design of Electromagnetic Acceleration for DPT

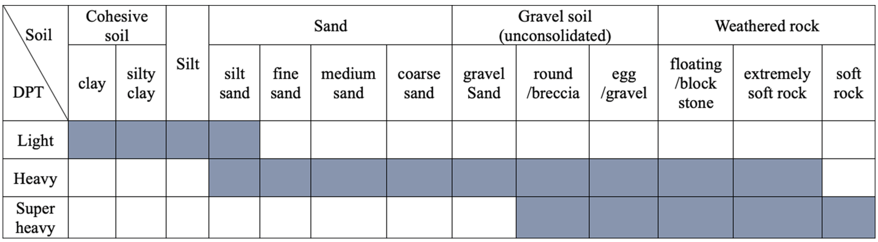

Fig. 1. Soil types corresponding to various types of dynamic sounding

Due to the spatial variability of the subsea geological soils, light dynamic penetration test can be applied to cohesive soil, silt and silt sand, most of which are on the offshore coast or on the undersea surface.However, as the depth increases, fine sand, medium sand, coarse sand, gravel, gravel soil and even very soft rock may be encountered [12]. At this time, it is necessary to increase penetration energy and switch part-stage acceleration to full-stage acceleration. In this way, adjustable and controllable electromagnetic hammer energy is achieved for the first time, switching between light, heavy, and super heavy dynamic penetration test [13].

Because power penetration test has certain standard, it is necessary to convert impact energy before designing driving circuit. Taking China's standard dynamic penetration test as an example, two types of dynamic penetration test impact energy are designed and converted. Considering the size and speed, a ferrous magnetic projectile with a radius of 25 mm and a length of 50 mm is selected as the projectile (Table 1).

Table 1. Design of ejection velocity of light and heavy DPT's projectile

M(kg)	g/(kg/m^2)	h(m)	v(m/s)	R(mm)	L(mm)	E(J)
10	9.8	0.5	3.13	/	/	49
0.771	/	/	11.27	25	50	49.00
63.5	9.8	0.76	3.86	/	/	472.95
0.771	/	/	35	25	50	472.64

It can be calculated that when the final velocity of the exit accelerator tube is 11.27 m/s, the impact energy is equal to that produced by the free falling motion of the light dynamic sounding hammer. When the final velocity of the exit accelerator tube is 35 m/s, the impact energy is equal to that of the free falling motion of the heavy dynamic sounding hammer.

2.2 Single-Stage Electromagnetic Acceleration Design

The structure of the single-stage projectile driving circuit is shown in Fig. 2. In the figure, the capacitance of the charging capacitor is C, the discharge system resistance of the circuit is R, and the equivalent inductance of the transmitting coil is L.

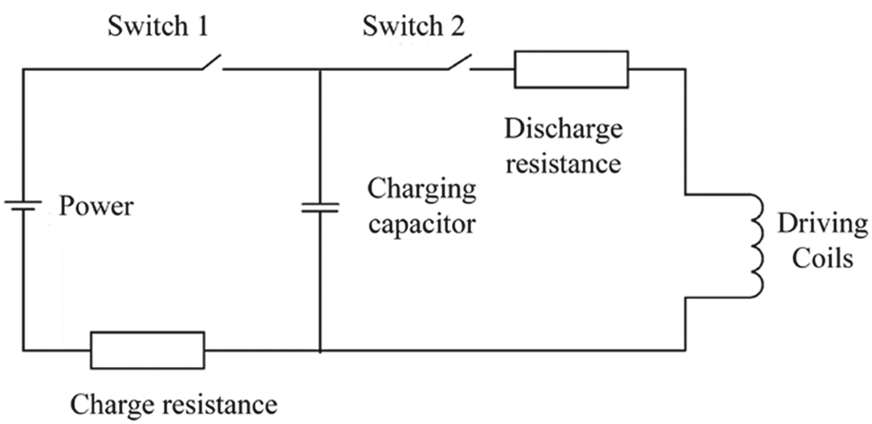

Fig. 2. Single stage drive circuit

According to the law of Kirchhoff:

$$L(x)C\frac{d^2u_c(t)}{dt} + \left(R + \frac{dL(x)}{dx} \times \frac{dx}{dt}\right)C\frac{du_c(t)}{dt} + u_c(t) = 0 \tag{1}$$

It is assumed that the drive coil has a core and the drive is cylindrical in shape. For the projectile, the length is l, the diameter is d, the density is ρ, the mass is m, the section area is S'.The electromagnetic force on the projectile is:

$$F_P(t) = \frac{KK'\mu_0\mu_r N^2 i^2(t)S'}{2l^2} \tag{2}$$

In equation, K and K' are linear coefficient, μ_0 is the vacuum permeability and μ_r is the relative permeability; N is the number of turns of the driving coils, $i(t)$ is the current flowing through the coil, and l is the length of the driving coils. It is further inferred that the projectile ejection velocity is:

$$v(t) = \int_0^t a(t)dt = \frac{KK'\mu_0\mu_r N^2}{2l^2\rho l'}\int_0^t i^2(t)dt \tag{3}$$

It can be seen from the above formula that the outlet speed of projectile in magnetoresistive electromagnetic launching is related to parameters such as turns of coil, length of coil, length of projectile, material of projectile, power supply voltage and discharge current (Fig. 3).

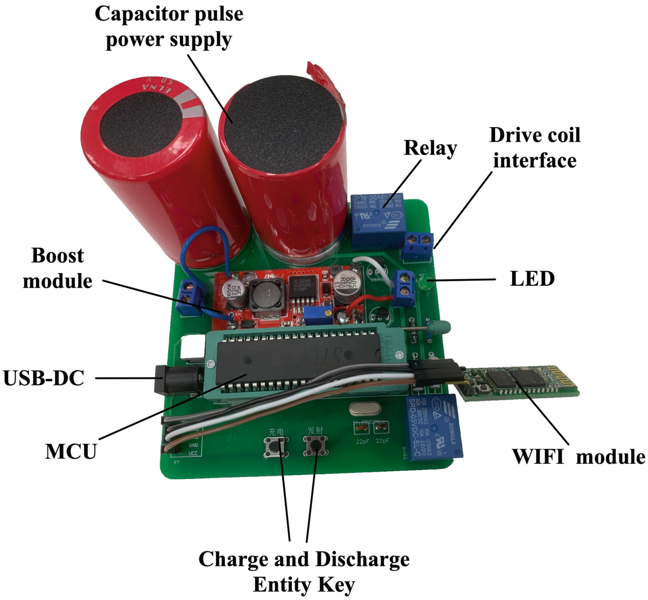

Fig. 3. Single-stage acceleration circuit board

The resistance of each part of the system affects the efficiency of electromagnetic emission. In actual system, the resistance of each part is closely related to the structure.

Therefore, the parameters affecting the launching efficiency of the system include the structure parameters of the driving coils and the projectile, the relative position between the projectile and the driving coils, and the triggering position parameters of the projectile passing through the driving coils at all levels.

The force acting on the projectile in the pulsed magnetic field generated by the driving coils can be divided into two parts: one part is the electromagnetic attraction between the projectile and the driving coils caused by the magnetization of the projectile, and the other part is the electromagnetic resistance between the eddy current induced on the cross section of the projectile and the magnetic field generated by the driving coils.

2.3 Multistage Electromagnetic Acceleration

The proposed multi-stage shot drive system consists of 8 driving coils, and a control chip with single-stage driving coils is set at each acceleration drive. It is mainly used to precisely control charge and discharge, so as to achieve higher energy conversion efficiency.

Driving coils are constructed in eight stages or as many other stages as required. Compared with single-stage electromagnetic emission of driving coil, multi-stage driving coils system can accelerate projectile more effectively, and the exciting power supply of each stage driving coils is relatively small, and the efficiency of launching system is also higher than that of single-stage electromagnetic emission.

Since the speed of the magnetic drive projectile will eventually be accelerated to a high degree and the energy transferred directly by impact with the output shaft will result in deformation and damage of the projectile, an energy buffer core is designed to transfer the energy of the projectile to the output shaft through the buffer, which will more softly transmit the energy. However, it is important to note that the energy loss in the projectile needs to be accounted for (Fig. 4).

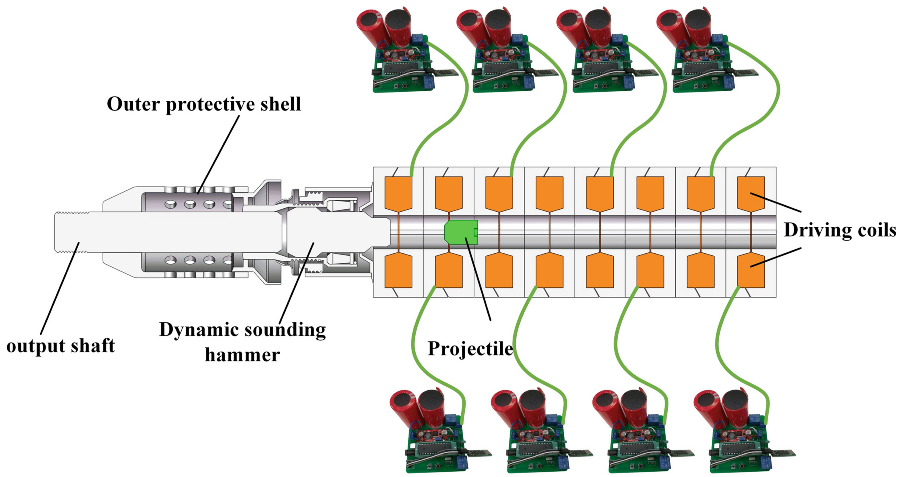

Fig. 4. Structural diagram of adjustable controllable electromagnetic emission system

The drive energy of the projectile comes from the driving coils, because the projectile was accelerated to be faster and faster, so the response of the stage-to-stage distance should become larger and larger. The distance between the multi-stage driving coils requires precise calculation and testing, and discharge acceleration takes place at the exact time during acceleration. Photoelectric sensors are added to the system to obtain the position of the projectile. When the projectile passes through to block the photoelectric signal, the next driving coils is triggered to open.

Emission efficiency is one of the most important technical indexes for launching reluctance coils, and is also the objective of parameter analysis and optimization de-sign. Ideally, if all the resistances, friction and air resistance in the electromagnetic launching system are ignored, the energy stored in the power supply can be fully converted into the kinetic energy of the projectile and the launching efficiency will reach 100%. According to the law of energy conversion and the law of energy conservation, the total energy of reluctance coil transmitter remains unchanged during the whole working process, such as the energy stored in the pulse energy storage capacitor, the heat energy generated by the system resistance, the electromagnetic energy generated in the driving coils, and the kinetic energy of the projectile movement, etc.

Assuming that the projectile passes through the acceleration of the electromagnetic gun and obtains a certain outlet speed, the projectile's kinetic energy E_K can be expressed as follows:

$$E_K = \frac{1}{2} m v_2^2 \tag{4}$$

In the equation, m is the mass of the projectile and v_2 is the outlet velocity of the projectile are used. The firing efficiency of the reluctance type electromagnetic gun is defined as η, the ratio of the increment of the kinetic energy of the projectile to the original stored energy of the pulse energy storage capacitor, i.e. the effective utilization of energy. The transmission efficiency of a multistage reluctance coil can be expressed as:

$$\eta = \frac{\frac{1}{2} m v_2^2}{\sum_{i=1}^{n} \frac{1}{2} C_i U_i^2} = e(r_1, r_2, l, l_2, r_3, r_4, N, C, U, v_1, s) \tag{5}$$

Formula: C_i is the capacity value of the capacitor, U_i is the initial voltage of the capacitor. r_1 is the inner diameter of driving coils, r_2 is the outer diameter of driving coils, l_1 is the length of driving coils, l_2 is the length of shot, r_3 is the radius of shot, N is the turns of driving coils and s is the triggering position of driving coils.

3 Conclusion

It is a completely new attempt to combine adjustable multi-stage acceleration system with impact dynamics for in-situ seabed dynamic penetration test. The problem of switching between different types of dynamic sounding has been solved and a new breakthrough has been made in the control accuracy of impact energy. More work needs to be done to solve the multi-stage coordination, and a stronger high-energy pulse power supply needs to be provided to drive a larger mass of projectiles. More precise control and energy transfer need to be studied to guide the study of multi-stage electromagnetic acceleration, physical manufacturing and sea trials will be achieved in the subsequent work.

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