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Hydraulic Vibration Hammer without Resonance Technology Status Study

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Short Communication

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ABSTRACT

Hydraulic vibratory hammer using the working principle of vibratory pile sinking is an important equipment in pile foundation construction, which can be used for sinking and extracting piles. It has a wider range of application than the drop hammer for pile sinking by the impact method and the static hammer for pile sinking by the press-in method, which can significantly reduce the resistance of piles during sinking and extraction and improve the working efficiency. However, it is difficult to avoid the resonance phenomenon in the process of starting and stopping by using the principle of vibratory pile sinking, and the resonance phenomenon will cause a high concentration of stress in the vibratory pile hammer parts and reduce its service life. In this paper, the resonance-free technology of hydraulic vibratory hammer is studied in the hope of promoting the development of hydraulic vibratory hammer. On this basis, the technology of innovative hydraulic vibratory hammer without resonance is used to reduce its cost and promote commercialization.

Keywords: Hydraulic vibratory hammer; vibratory pile-sinking; resonance-free.

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1. INTRODUCTION

Hydraulic vibratory hammers have been playing an important role in the construction of bridges, ports, flood control and urban residential projects, and with the rapid development of China's economy, the demand for hydraulic vibratory hammers is increasing day by day [1-4]. Hydraulic vibration hammer work, the use of hydraulic motor driven by the active shaft rotation, by a group or more groups of eccentric wheel rotation in the same direction to generate the vertical direction of the excitation force [5]. under the action of the periodically changing excitation force to make the pile and the surrounding soil vibration, periodic vibration can reduce the pile side and the frictional resistance between the soil particles, the pile rely on self-weight to overcome the pile side frictional resistance and pile tip resistance and penetrate the ground sinking [6]. The structural composition of the hydraulic vibratory hammer is shown in Fig. 1.

Currently, the method to dispense with resonance of hydraulic vibratory hammer is mainly by modifying the exciter of the vibratory hammer, which is time-consuming, difficult and costly to study.

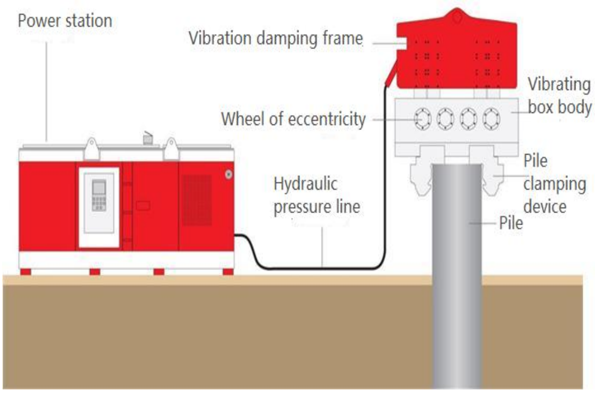

Fig. 1. Structural composition of the vibratory hammer

2. DEVELOPMENT OF HYDRAULIC VIBRATORY HAMMERS

The theory of sinking piles by vibration was developed in the 1930s [7]. Pavyluk in the former Soviet Union discovered that vibration reduces the shear strength of the soil, resulting in a reduction in soil friction, and thus introduced the concept of vibratory pile sinking [8]. In 1931, Barkan found that vibratory pile sinking reduced the friction between the side of the pile and the soil to a much greater extent than conventional pile sinking [9]. In 1934, he invented the world's first vibratory hammer based on the principle of "liquefaction" of vibration [10]. The basic principle of high frequency vibratory piling was elaborated in 1949 [11]. In 1950, Tatarnikov of the former Soviet Union designed the BII-1 vibratory hammer for sinking reinforced concrete piles [12]. In 1959, Japan successfully developed the first electric vibratory hammer [13]. In the 1960s, the United States developed the hydraulic vibratory hammer [14]. The development of the vibratory hammer is shown in Fig. 2.

Vibrating hammer is divided into electric type vibrating hammer and hydraulic type vibrating hammer [15]. Electrodynamic vibratory hammer in the work process produces a large energy loss, because the use of electric drive and can not be applied to marine engineering, while the hydraulic vibratory hammer can be applied to the water or underwater operations [16]. Because of the hydraulic components to transfer power more convenient, less noise, so the hydraulic vibration hammer is more commonly used [17].

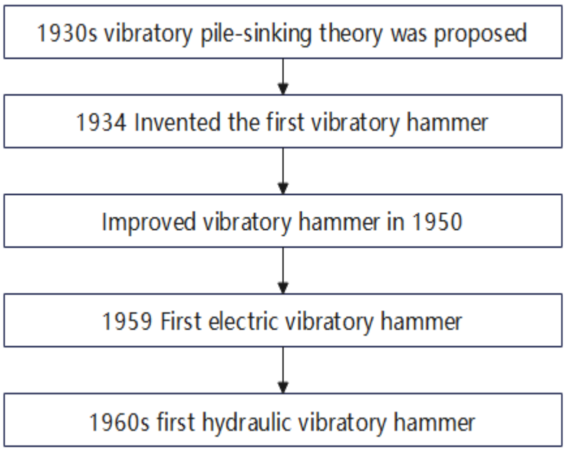

Fig. 2. Development of vibratory hammers

3. RESEARCH STATUS OF RESONANCE-FREE TECHNOLOGY OF HYDRAULIC VIBRATORY HAMMER

Hydraulic vibratory hammer enhances the piling efficiency, but it is difficult to avoid the resonance phenomenon during the starting and stopping process of hydraulic vibratory hammer [18]. Therefore, when the pile hammer accelerates or decelerates through the self-oscillation frequency area, it will resonate for a short period of time, causing a high concentration of stress in the pile hammer parts and reducing its service life [19]. The working process of hydraulic vibratory hammer resonance frequency interval diagram is shown in Fig. 3.

3.1 Study of Vibratory Hammer Exciters

Some researchers firstly investigated the dynamic properties of the vibratory hammer. Liu Guihua et al. [20]. studied the dynamic performance of vibratory hammer and found the effect of the variation of vibratory hammer amplitude on the efficiency of vibratory hammer when sinking and extracting piles by studying the differential equations of motion of vibratory hammer, which provided a theoretical basis for the design and development of the system of vibratory hammer amplitude adjustment mechanism for achieving higher efficiency in sinking and extracting piles. Zhou Linsen et al [21]. studied the dynamics model of two-degree-of-freedom vibratory impact hammer, used the first harmonic to describe the nonlinear interval impact force of the vibratory hammer, and obtained the dynamic parameters of the vibratory hammer by calculating and solving the system of differential equations of motion, which provided the basic theory and method for the in-depth study of the dynamics characteristics of the vibratory hammer. Based on the working principle and main parameters of the vibrating hammer, Yu Guoping established a dynamics model and solved the dynamics equations to find out the dynamic response of the system under the action of the excitation force. The study of the dynamics of the vibratory hammer provides a theoretical basis for the study of the working process of the vibratory hammer [22].

Then the researchers studied the mathematical model during the working process of the vibratory hammer. Li Husheng studied the two-degree-of-freedom mathematical model during the working process of hydraulic vibratory pile hammer and used Matlab software to simulate and analyze the two-degree-of-freedom mathematical model during the working process of hydraulic vibratory pile hammer, and obtained the vibration hammer displacement, velocity and acceleration during the vibration hammer [23]. Zhang et al. [24] established the equations of motion of the pile sinking process during the operation of the vibratory hammer according to the structural dynamics and calculated the amplitude during the pile sinking process, and the obtained calculation results provide guidance for the vibratory hammer to mitigate the resonance phenomenon and avoid excessive amplitude. Wang Kai et al. [25] established a finite element model by simplifying the vibratory hammer and soil, and simulated the pile sinking process of the vibratory hammer by using ANSYS software to obtain the influence curves of excitation force frequency, excitation force, and mechanical properties of soil on the pile sinking of the vibratory hammer, and the obtained curves can reflect the unreasonable parameters of the pile driver. For the simulation level of vibratory hammer in China, Yunfei Jiang et al. [26]. First carried out the solution of the two-degree-of-freedom mathematical model of the vibratory hammer to derive the expression of the regular relationship between amplitude and frequency, and used Matlab software to simulate the amplitude-frequency response under different parameters, and obtained the relationship between the amplitude of the beam and the sunken pile and each parameter. The study of the mathematical model during the operation of the vibratory hammer provides support for the study of the prototype of the vibratory hammer.

Tao Li performed dynamics analysis and modeling simulation on the experimental prototype of vibratory hammer, and found the laws of pile end resistance, pile side friction resistance, sinking pile displacement and velocity change with time [27]. Liu Wei took ZZY160 vibrating hammer as the research object, and studied the system of vibrating hammer and soil separately, and discovered the frequency characteristics of the working process of the vibrating hammer [28]. By studying the principle of eccentric moment adjustment, he designed and manufactured the hydraulic frequency and amplitude adjustment system, which realized the change of eccentric moment by changing the eccentric distance, and used the stepless adjustment and remote control of the hydraulic control system to realize the frequency and amplitude adjustment of the vibration hammer. Wu Shuai et al. [29] used Adams software to simulate the 3D model of the inertia hammer and obtained the curves of the motion trajectory of the hammer under different initial parameters, and then obtained the displacement, velocity and acceleration of the parts, so as to find the unreasonable parameters and optimize the design of the pile driver. Bian Hongye et al. [30]. studied the hydraulic system of the vibratory hammer and the pile and soil system of the pile sinking process with the new hydraulic vibratory hammer, modified the structure of the vibratory hammer and the hydraulic system, and simulated the pile sinking process of the vibratory hammer using ANSYS software to obtain the vibration curves of the vibratory hammer under different parameters.

By comparing the data, the relationship between the vibration parameters of the vibratory hammer and the effect of sinking and extracting piles was obtained. By reasonably selecting the vibration parameters of the vibratory hammer, the resistance of sinking piles can be overcome and the effect of sinking and extracting piles can be improved by increasing the impact force of piles on soil [31].

Some researchers have studied the exciter of the vibratory hammer immediately afterwards. Fu Maojing designed a new broadband shaker that excites in the frequency range of 20 Hz to 20 kHz [32]. The new broadband shaker combines electrodynamic excitation with piezoelectric excitation. The no-load acceleration and force-frequency response of the new shaker passed a series of tests to verify the possibility of the new shaker and provide a reference for the improvement of the vibration hammer. Qingkai Han et al. [33]. studied the vibration system with reverse rotary excitation, established the kinetic equations for the drive motor, and obtained the influence law of the eccentric moment of the shaker, motor power, eccentric rotor rotary frictional resistance moment and other parameters on the self-synchronous motion through software simulation analysis. A theoretical basis was provided for the design and development of the vibration hammer. Luo Chunlei et al. [34] designed a new type of hydraulic vibratory pile hammer exciter and its hydraulic control system. The designed hydraulic vibratory pile hammer exciter is a four-axis vibratory pile hammer structure, and the hydraulic cylinder oil pressure is not used to adjust the gear, and the eccentric block is driven by the hydraulic cylinder to produce changes in eccentric distance; the designed hydraulic control system realizes one valve for multiple uses, and takes into account various conditions during operation, which provides safe operation and efficient operation. The designed hydraulic control system achieves multiple uses of one valve and considers various conditions during operation, providing a guarantee for safe and efficient operation. Che Renwei et al. [35] designed a new vibratory hammer exciter, established a vibration model, and further carried out a dynamic analysis of the system, and found that in the process of sinking and extracting piles by vibratory hammer, the magnitude of the excitation force is related to the eccentric distance, and changing the magnitude of the amplitude can make the vibratory hammer sink piles faster. These studies provide a theoretical basis for the design and research of resonance-free vibratory hammers.

Zhao Yucheng et al. [36] designed a new type of eccentric wheel mechanism, which can produce wide frequency excitation and can improve the working efficacy of the vibratory hammer and expand the working range of the vibratory hammer. The dynamics model was established by combining the working process of the vibratory hammer, and the simulation analysis was carried out for different time periods during the operation process to verify the feasibility of the eccentric wheel mechanism and provide a reference basis for the improvement of the vibratory hammer. Feng Haifeng conceived and designed a new type of resonance-free electrodynamic vibratory pile hammer, and made a detailed introduction to the principle of resonance-free eccentric wheel [37]. The simulation of eccentric wheel motion was made by MATLAB simulation software to verify the vibration avoidance capability of the eccentric wheel, and different excitation forces were obtained by adjusting the relationship between the parameters to meet the requirements of different working conditions.

3.2 Study of Novel Resonance-Free Methods

The hydraulic vibratory hammer exciter modification is ineffective and time-consuming [38]. Therefore, by improving the structure of the machinery, so that the excitation frequency of the machinery to avoid the inherent frequency; through the energy transformation, so that the mechanical start or stop process quickly through the resonance zone has become a new way to eliminate resonance hydraulic vibration hammer.

Chen Jianye et al. [39] designed the metal compression spring as the vibration damping element of the vibration hammer by using the reliability design method for the violent vibration phenomenon during the operation of the vibration hammer, and the design check of the vibration damping spring was carried out by calculation, which provided the theoretical basis for the design and development of the vibration hammer. Zhou Hongxia used AMESim software to simulate the hydraulic vibration hammer model, analyzed the parameters affecting the resonant frequency of the system, and found that the resonant frequency of the system is determined by the length of the rodless cavity of the hydraulic cylinder, and the length of the rodless cavity can also affect the magnitude of the excitation force, which provides a reference for adjusting the resonant frequency of the hydraulic vibration hammer [40].

Shanghai Zhenzhong Company uses adjustable eccentric distance technology to solve the resonance problem of hydraulic vibration hammer [41]. This technology is through the adjustment mechanism to change the relative position of the eccentric wheel so that the amplitude can be adjusted. When the vibration hammer starts to reach the resonance frequency, the relative phase angle of the eccentric wheel is adjusted so that the eccentric moments of the relative eccentric wheels cancel each other and no vertical excitation force is generated, thus eliminating the disturbance vibration in the starting process. The principle of adjustable eccentric distance technology is shown in Fig. 4. The DZP resonance-free frequency conversion vibration hammer developed by Shanghai Zhenzhong Company adopts inverter frequency conversion, and by adjusting different vibration frequencies of vibration hammer work, the working frequency of vibration hammer is rapidly raised when starting, while using energy conversion system, the kinetic energy of eccentric wheel rotation is quickly converted into electric energy, and the reserve electric energy is finally converted into heat energy, so as to avoid resonance phenomenon.

Yu Kun optimized and improved the hydraulic control system of vibration hammer, designed the hydraulic soft start controller and ran it in LabVIEW software, and conducted comparative experiments on the vibration hammer experimental prototype with hydraulic soft start control. The experimental results obtained through sensors verified that this hydraulic soft start controller could make the hydraulic vibration hammer attenuate resonance in the starting stage [42].

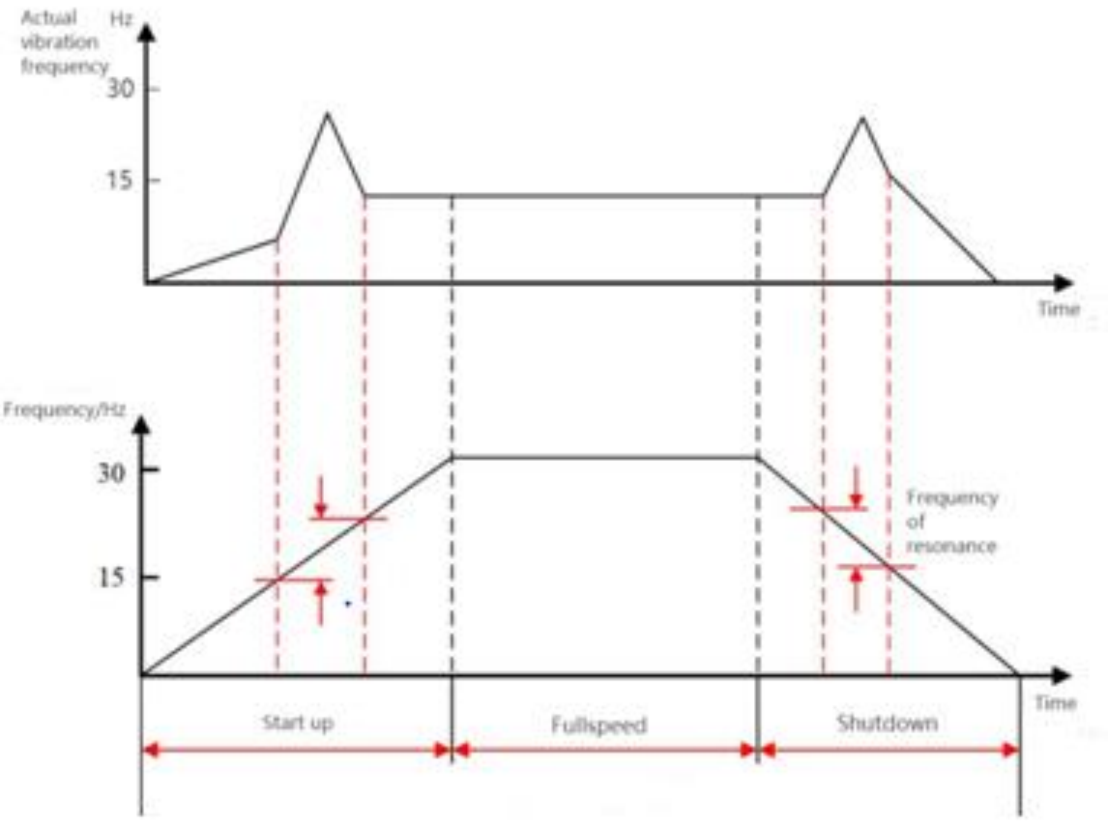

Fig. 3. Schematic diagram of the resonant frequency interval of the working process of hydraulic vibratory hammer

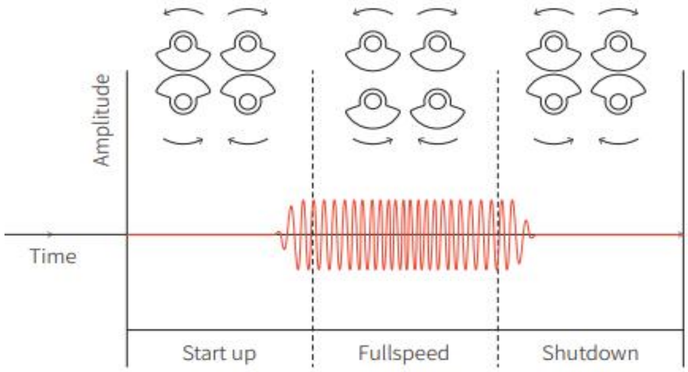

Fig. 4. Principle of adjustable eccentricity technology

4. CONCLUSION

In summary, by improving the structure of the machinery, so that the mechanical excitation frequency to avoid the inherent frequency; through energy transformation, so that the mechanical start or stop process quickly through the resonance zone is an important development direction of the hydraulic vibration hammer without resonance. The resonance-free technology of hydraulic vibratory hammer has been studied in depth, and important progress has been made. The transformation of the exciter of hydraulic vibratory hammer does not give good results, and the transformation of the mechanical structure of hydraulic vibratory hammer can achieve better results through energy transformation, so that the rapid passage through the resonance zone can achieve better results, and the resonance-free hydraulic vibratory hammer has put forward higher requirements.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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