The Research of Mechanical Vibration Exciter of the High-Speed Rail Subgrade Dynamic-Response

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Abstract: According to the scheme made by Institute of Mechanics, Chinese Academy of Sciences on mechanical vibration exciter of the high-speed-railway subgrade dynamic-response, when such vibration exciter, simulating trains with different hourly speeds, makes vibratory shocks on the subgrade, the exciter should be minimized in its horizontal displacement. The work starts with the mechanical model of the exciter movement mechanism. It is found by analyzing the mechanical model of a single eccentric wheel that home-position vibration is achievable theoretically if the mechanism adopts dual eccentric wheels that run in opposite directions. With the built theoretical model in mind, practical position-limiting measures are taken so that the exciter's horizontal displacement does not exceed 10mm. It turns out that the movement mechanism of this vibration exciter satisfies the actual operational requirements.

Keywords: Eccentric wheel, Centrifugal force, Subgrade dynamic response, vibration exciter.

Introduction

High-speed rail transport is an advanced way of transport, it started late in our country but developed rapidly. With the increasing of the speed and load of the train operators, long-term stability of the subgrade also increasingly been taken seriously. To reduce accidents, it is necessary to test the subgrade structure. Model tests and in situ test are two common dynamic response test methods of the subgrade. Mechanics of Chinese Academy of Sciences study on dynamic response of high-speed rail subgrade use in situ test, vibration exciter is the key equipment in situ testing system.
In this paper, according to the development of programs on high dynamic response based on railway mechanical excitation device by Chinese Academy of Sciences to design the vibration exciter to meet the requirements.

Development program of mechanical vibration exciter

According to the mechanical properties and natural frequency of subgrade’s material, it requires that the exciting frequencies of vibration exciter reach to 5 ~ 40 Hz, the excitation amplitude reach to 0.4 ~ 2mm, the exciting force reach to 60kN. The vibration exciter must meet the following demands:

1) Vibrator and hydraulic motor must use the split design to ensure the effects of high-frequency, high amplitude vibration and design the hydraulic motor of power source for the active hydraulic station;

2) Use the control panel to control the vibrator, which can provide stable and continuous changes in the vibration frequency to achieve different load frequencies;

3) There are screw holes at the bottom of the vibrator that can be connected to different dimensions of the bearing plate, provide dynamic stress of different sizes to simulate different axle load of the train; There are vibration washers between the vibrator plate and the bearing plate to reduce collisions between two steel plates;

4) To design a guide frame on a shaker to limit the horizontal displacement of the vibrator and ensure the relative concentration of vibration, keep a certain gap between the vibrator and the guide frame and take some methods to reduce collisions;

5) Reduce the impact of the vibrator inlet pipe for balancing the vibrator, design appropriate inlet pipe direction;

6) Particular emphasis on the special nature of railway subgrade’s soil, when vibrator is on continuous operation, its horizontal displacement should less than 10mm.

According to the introduction of the development program, this paper focuses on solving the problems of theoretical modeling of the exciter and restrictions on horizontal displacement.

Mechanical model of the vibration exciter

1. Mechanical analysis

From the mechanical model of the movement mechanism of the exciter, Firstly, make mechanical analysis of the Exciter movement mechanism with the mechanical model of a single eccentric wheel, [1,2] as shown in Fig.1.
Figure 1. The mechanical model of a single eccentric wheel.

AC - Bottom of the vibration exciter; O' - The rotation center of eccentric wheel; O - Gravity center of the vibration exciter; G - Total weight of the vibration exciter; $F_n$ - Centrifugal force of the vibration exciter; $\theta$ - Turn corner of eccentric wheel;

$\omega$ - Rotational angular velocity; $\theta_e$ - The rise angle of the vibration exciter

When the turn corner of eccentric wheel is $0^\circ$, there are no sub force in $Y$ for $F_n$, the vibration exciter flats on the ground at this time, at the same time, it is effected by friction $f_n$ and its own gravity $O$, velocity of the vibration exciter is 0. With the turn of the eccentric wheel, when the angle $\theta \in (0^\circ \sim 90^\circ)$, the sub force $F_{ny}$, $F_n$ on $Y$, turn up and increases, the point $A$ under the vibration exciter begin to rise around point $C$. This process is known as "the rise of phase"[3,4,5]; when $F_{ny}$ big enough, turn corner of eccentric wheel $\theta \in (90^\circ \sim 180^\circ)$, vibration exciter starts to leave off the ground, face friction $f_n$ disappear at this time, vibration exciter will be effected by sub force $F_{nx}$ of $F_n$ on $X$ and flight period on the horizontal direction, known as the "flight phase"; when $\theta > 180^\circ$, $F_{ny}$ is downward direction, vibration exciter fall under $F_{ny}$ and its own gravity, when $\theta$ near $270^\circ$, with the hysteresis of the gravity center of the vibration exciter, point $C$ contact with the ground first, further impact on the ground needed to be reinforced, this is the "fall" and "reinforce" stage[6].

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From above analysis, using a single eccentric wheel may experience "rise", "Flight", "falling", "reinforce" the four stages. If use dual eccentric wheels running in the opposite direction at the same time, rely on their centrifugal force strike the ground, then the vibration exciter is possible to achieve in-situ. This paper focused on the design of mechanical model lies in the use of dual eccentric wheels turn reverse direction synchronously, there are two horizontal acting force $F_{n1x}$ and $F_{n2x}$ on the direction $X$, if two eccentric wheels completely symmetrical, these two forces are equal and opposite directions and cancel each other out, it effected by centrifugal force on the direction $Y$ and strike the ground and vibration-situ. Dual eccentric wheels movement mechanics analysis is shown in Fig.2.

![Figure 2. The mechanical model of dual eccentric wheels.](image)

- $O'$ - The center of rotation of eccentric wheel 1; $O''$ - The center of rotation of eccentric wheel 2;
- $F_{n1}$ - Centrifugal force of eccentric wheel 1; $F_{n2}$ - Centrifugal force of eccentric wheel 2;
- $\theta_1$ - Turn angle of eccentric wheel 1; $\theta_2$ - Turn angle of eccentric wheel 2;
- $\omega_1$ - Rotary angular velocity of eccentric wheel 1; $\omega_2$ - Rotary angular velocity of eccentric wheel 2;
- $N$ - The impact of the vibration exciter.

This theoretical modeling analysis is based on the assumes that two eccentric wheels are completely symmetrical, it is theoretically-situ vibration. Consider to two eccentric wheels’ actual construction process, may not appear completely symmetrical, then the vibration exciter will produce small displacement in the process. Certainly, according to the actual situation analysis, if the technology construction can make two eccentric wheels completely symmetrical, simulating continuous work on the subgrade with the vibration exciter, roadbed soil is compacted tightness vary, action and reaction on the subgrade are random variables, so it will cause the exciter produces little displacement during vibration. Development scheme that proposed by Mechanics of Chinese Academy of Sciences require that the horizontal displacement of the vibration exciter is less than 10mm during its continuous work. Based on the
Theoretical analysis and combined with the actual situation, to design limit exciter mechanism.

Limit design of mechanical vibration exciter

As the preceding analysis, many uncertain factors will directly affect the level of vibration exciter during vibration, how to limit the horizontal displacement is a worldwide problem in the field of mechanical engineering. To meet the requirement of Mechanics of Chinese Academy of Sciences, according to our research on the vibration machine for many years, we designed a simple and reliable limit programs, playing four iron pickets in the four corners of the vibration exciter box spaced certain subgrade foundation where allowed, then pull exciter with slick line. Simple position-limiting diagram is shown in Fig.4. Positioning plate can be flexibly adjusted according to the depth of the roadbed scored by the iron pickets in figure (a), the iron pickets is 2.5m away from the center of the exciting center $b$, as the distance of $a$, $b$ in the figure. One end that rope attached to the exciter is lead out from $c$ which about 30mm away from the ground. The other end of the rope is fixed to $d$ on the iron pickets, the angle $\alpha$ between the straight line $cd$ and the horizontal direction is appropriate $30^\circ$, it is more effort in this direction to pull exciter. Taking the impact of the rope by its own gravity into account, the rope will naturally droop in the lower part, and it will touch the subgrade during vibration and cause some degree of damage, so we install spring in the middle of the rope to avoid it, as figure (b). If vibration exciter has horizontal displacement, wire rope gradually tensioned by spring and stretches tight straight finally to limit the horizontal displacement of not more than 10mm, as figure (c).
1- Iron pickets; 2- Positioning plate; 3- Wire Rope; 4- vibration exciter; 5- Spring
Figure 4. Position-limiting diagram.

Summary

This paper studied the mechanical vibration exciter of the high-speed rail subgrade
dynamic-response from the theoretical modeling analysis to design practical limit.
Modeling analyzes exciter movement mechanism theoretically, proposed that
mechanical model of dual eccentric wheels can realize in situ vibration exciter; then
according to engineering reality, give a set of simple and practical limit solutions to
simulation how to limit the horizontal displacement issues when different speed trains
shock and vibration exciter on the subgrade, it has practical value.

References

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