Research and Development of Hydraulic Controlled Vibration Damper with Vibration Energy Absorption

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Abstract. Research on the core technology has obtained a patent for invention authorization of hydraulic controlled vibration damper with vibration energy absorption. The hydraulic cylinder structure is designed by the principle of liquid incompressibility. The hydraulic circuit increases and the gap distance changes due to the movement of balance plate under the pressure difference between the two chambers of the hydraulic cylinder. With the damping effect and pressure drop of liquid flow, the purpose of efficient vibration reduction is achieved by absorbing the vibration energy into heat. The invention patent of the self-tuning hydraulic vibration energy absorption is suitable for the situations with high speed, precision, light load and small and medium energy level. For example, the measurement accuracy is improved by vibration reduction with dynamic weighing in instrument. And the processing precision is achieved by vibration reduction for precision machine tools. The invention patent of high power hydraulic emergency energy absorption for multistory parking area is applicable to the conditions with high altitude fall, impact, collision and large-scale energy absorption, such as elevator emergency energy absorption safety devices, the bases of forging press machine tools, high-speed rail locomotive vehicle chassis, and so on.

Keywords: Hydraulic controlled · Vibration damper · Vibration energy absorption

1 Introduction

With the development of science and technology, modern vibration dampers have broad application prospects in some special environments and scenes, such as engineering machineries, machine tool equipment, construction machineries, high speed rail vehicles and dynamic working environments, and so on and so forth. Those are commonly used in concrete mixer truck weighing devices and high lift elevator safety devices. Beyond the working area, vibration damping and vibration elimination are usually required for non-executive components, especially for mechanical equipment working in vibration mode, such as vibratory roller, vibration drill, crusher, percussion drill, vibrating screen and so on [1–4].

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Research on the core technology has obtained a patent for invention authorization of hydraulic controlled vibration damper with vibration energy absorption [5–8]. The hydraulic cylinder structure is designed by the principle of liquid incompressibility. The hydraulic circuit increases and the gap distance changes due to the movement of balance plate under the pressure difference between the two chambers of the hydraulic cylinder [9–11]. With the damping effect and pressure drop of liquid flow, the purpose of efficient vibration reduction is achieved by absorbing the vibration energy into heat. Thus, the noise pollution produced by the vibration is reduced [12–14].

2 Self-tuning Hydraulic Vibration Energy Absorption

Self-tuning method and device for hydraulic vibration energy absorption are authorized a national patent for invention of China in 2013: ZL2011 10117133.3.

2.1 Basic Structure

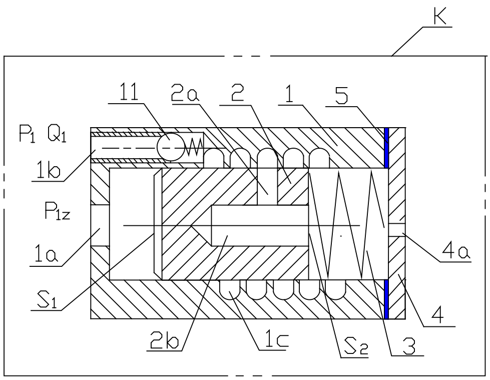


Fig. 1. Basic structure of self-tuning hydraulic vibration energy absorption device.

Where: 1-damping shell, 2-piston slider, 3-pressure differential equilibrator spring, 4-end cover, 5- prepressed adjusting shim, 1a-vibration wave receiving hole, 1b-liquid resistance channel, 11-check valve, 4a-oil return port, 1c-liquid resistance spiral groove, 2a-radial pressure drop channel, 2b-axial steady flow chamber.

As shown in Fig. 1, the self-tuning hydraulic vibration energy absorption device is composed of damping shell 1, piston slider 2, pressure difference equilibrator spring 3, end cover 4, prepressed adjusting shim 5, vibration wave receiving hole 1a, liquid resistance channel 1b, check valve 11, oil return port 4a, liquid resistance spiral groove 1c, radial pressure drop channel 2a, axial steady flow chamber 2b. The adjustable piston slide block 2 is located in the inner cavity of the damping shell 1 and seals with the inner cavity wall. The right side of piston slider 2 and the left end of the pressure differential equilibrator spring 3 fit together. The right end of pressure differential equilibrator spring 3 is connected with the end cover 4 with the oil return port 4a in the center. The prepressed adjusting shim 5 is located between the end cover 4 and the damping shell 1. And there is a check valve 11 in the liquid resistance channel 1b.

There is an inner cavity in the middle of the damping shell 1 and the liquid resistance channel 1b on one side of the damping shell. In the center of the section, the vibration wave receiving hole 1a is connected with the inner cavity. There is the liquid resistance spiral groove 1c on the side wall of the inner cavity, which links up with the liquid resistance channel 1b. The piston slider 2 is a cylinder with an axial blind hole called the axial steady flow chamber 2b in the center. On the side of the cylinder, the radial hole which is named the radial pressure drop channel 2a is connected with the axial steady flow chamber 2b. The pressure differential equilibrator spring 3 is a variable force spring or a memory shrapnel. The prepressed adjusting shim 5 can be a rigid or elastic shim.

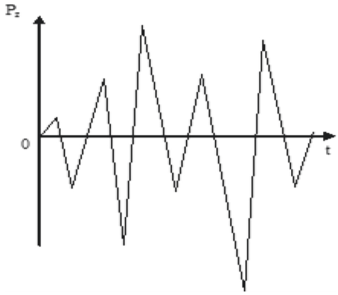
2.2 Principles

The wave energy produced by the vibration source enters the inner cavity of the damping shell 1 through the vibration wave receiving hole 1a [15–18]. The effect of oil pressure P_1 and vibration wave pressure P_{1z} is on the left end S_1 of the piston slide block 2 simultaneously, at the same time, the energy P_1Q_1 of the vibration source can enter the liquid resistance channel 1b. The damping and depressurization of the vibration energy is accomplished through liquid resistance spiral groove 1c in the form of heat radiation. Passing through the depressurization channel into the anti-surge chamber, the vibration energy after the flow-stabilizing enters the returning line. Thus, the oil pressure P_2 is brought on the right end S_2 of the piston slider 2. The piston slider 2 moves to the right under the action of the oil pressure P_1. The flow resistance loss becomes larger due to the length of the liquid resistance spiral groove with oil increases. The pressure differential equilibrator spring 3 is compressed with the reverse thrust increasing. The instantaneous peak amplitude response of vibration waves decreases rapidly [19–21]. The piston slider 2 is adjusted to the left under the synthesis thrust of the pressure difference equilibrator spring 3 and the oil pressure P_2, which is greater than the thrust produced by the oil pressure P_1. The number of oil pressure P_2 extends and the length of the liquid resistance spiral groove with oil gradually decreases with vibration energy reduction. The equilibrium between both ends of the piston slider 2 (S_1 and S_2) is achieved. The amplitudes applying on both sides of the piston slider counteracts each other at the same time, thus the impact of the vibration source is avoided. When the vibration wave is at the negative peak, the slide block repeats the steps above automatically eliminating the adverse effects to achieve a new balance.

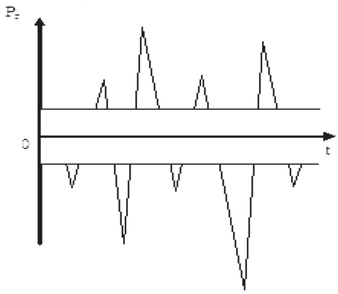
The self-tuning hydraulic vibration energy absorption devices can be installed in pairs with a reverse one for better damping effect [22].

The change of vibration waveforms before and after self-tuning is shown in Fig. 2 [23–25].

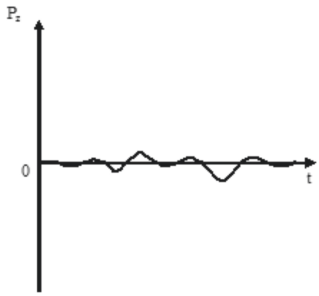
Working principles: The external vibration signals is divided into two parts [26–30]: one part of the signals passes through vibration wave receiving hole 1a to the left side S_1 of piston slider 2. The extent of shaking force is determined according to the effective area of the side on the left S_1. The pressure decreases from P_{1z} to P_{2z} as other part of the signals receives the right side S_2 in the damping shell 1 with the rate of flow Q_1 through the path 1b-2a-2b-S_2. According to the effective area of the right side S_2, the energy



(a)Vibration wave



(b)Before self-tuning



(c)After self-tuning

Fig. 2. Vibration waveforms before and after self-tuning.

consumption and the vibration force counteraction are calculated by the whole process of liquid flow through S_1 to S_2 [31–33]。The receiving, measuring and calculating of vibration power consumption is completed. The equilibrium position of piston slider 2 is determined under the synthesis thrust of the pressure difference between both sides (S1 and S2) and the pressure difference equilibrator spring 3. The purpose of completely eliminating vibration force by hydraulic damping is achieved and the system is in the steady state.

2.3 Characteristics and Innovation Points

The features and innovations of invention patent (Self-tuning method and device for hydraulic vibration energy absorption: ZL2011 1 0117133.3) are listed as follows [5].

(1) In the prior art, the inner diameter of the valve bore is invariable, which is not adjustable, movable or of self-setting characteristics. When the vibration energy acts on it, the piston bounces up and down in oil due to the wave shock. The reaction is played on the vibration source and the damping effect is reduced. Due to the structural design, the damping length and pressure drop of the liquid resistance spiral groove are automatically adjusted with the change of the vibration energy. The complicated and changeable vibration energy is absorbed by adjusting the positions of the piston slider 2 and pressure differential equilibrator spring 3. The impact of the vibration energy on the vibration source is ingeniously avoided as the self-adjustment and cancellation of wave transmission characteristics.
(2) The piston moving produced by the vibration squeezes the oil passing through the liquid resistance spiral groove. The huge liquid damping and pressure drop are formed to absorb the vibration energy and the shock absorption is achieved.
(3) The vibration wave is counterbalanced by the adjustable slider to avoid the interference back to the vibration source. The energy is absorbed in time by self-setting and the frequency of reciprocating vibration is reduced for the purpose of great damping effect.

3 High-Power Hydraulic Emergency Energy Absorption for Multistory Parking Area

The invention patent authorization with the method and device of high-power hydraulic emergency energy absorption for multistory parking area is obtained in 2015 (ZL2013 10217678.0) [30]. And the manual hydraulic energy absorption method and device for emergency protection of multistory parking area is authorized as a national patent for invention of China in 2015 (ZL2013 10217657.9) [34].

3.1 Structure Diagram of Hydraulic Energy Absorption Device Controlled by Analog Variables

As shown in Fig. 3, the hydraulic energy absorption device [35] is controlled with analog variables. It consists of energy absorption shell 1, elastic supporting mechanism 2, sealing strip 3, top cover 4, floating pressure equilibrium side-panel 5, front and rear end cap 6, control valve housing 7, movable support gasket 8, cone valve core 9, conical valve spring 10, regulating handle 11, return oil piping for control circuit 12, oil tank 13, pressure sensor in the upper plenum chamber 14, pressure sensor in the lower internal consumption cavity 15, servo stepper motor 16, control computer 17, potential difference comparator 18, output pulse control signal circuit 19, input control signal circuit 20, signal conversion module for pressure sensor in the upper plenum chamber 21, signal conversion module for pressure sensor in the lower internal consumption cavity 22, main oil inlet a, main oil outlet b, lower internal friction cavity C, upper plenum chamber D, connection hole between the upper and lower cavities E, lower internal friction cavity gap δ, lower inner friction cavity width L, oil intake control port K_1 and oil outlet control port K_2.

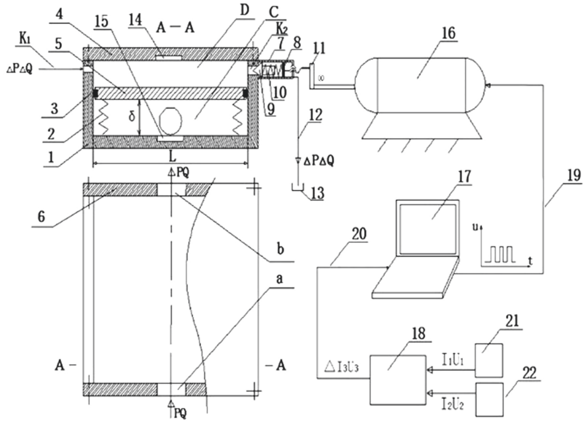


Fig. 3. Structure diagram of hydraulic energy absorption device controlled with analog variables.

Where: 1-energy absorption shell, 2-elastic supporting mechanism, 3-sealing strip, 4-top cover, 5-floating pressure equilibrium side-panel, 6-front and rear end cap, 7-control valve housing, 8-movable support gasket, 9-cone valve core, 10-conical valve spring, 11-regulating handle, 12-return oil piping for control circuit, 13-oil tank, 14-pressure sensor in the upper plenum chamber, 15-pressure sensor in the lower internal consumption cavity, 16-servo stepper motor, 17-control computer, 18-potential difference comparator, 19-output pulse control signal circuit, 20-input control signal circuit, 21-signal conversion module for pressure sensor in the upper plenum chamber, 22-signal conversion module for pressure sensor in the lower internal consumption cavity, a-main oil inlet, b-main oil outlet, C-lower internal friction cavity, D-upper plenum chamber, E-connection hole be tweeen the upper and lower cavities, δ-lower internal friction cavity gap, L-lower inner friction cavity width, K_1 -oil intake control port, K_2-oil outlet control port.

3.2 Working Principles for Hydraulic Energy Absorption Device Controlled with Analog Variables

(1) The main energy absorption process: the liquid PQ with energy flows within the lower internal friction cavity C to the upper plenum chamber D through the cross section formed by the lower internal friction cavity gap δ and width L after entering the main oil inlet a. And the pressure of lower internal friction cavity is reduced from P_c to $\triangle P_0$. Regulating handle control circuit: the control oil $\triangle P \triangle Q$ enters the upper plenum chamber D through oil intake control port K_1. The cone valve core 9 moves right to open the oil outlet control port K_2 when the pressure can overcome the pre-tightening force of the conical valve spring 10. Thus, the liquid flows to the oil tank 13 through the oil outlet control port K_2 and return oil piping for control circuit 12. If the liquid remains flowing, the pressure of upper plenum chamber D is considered as a constant value. The difference between the product of the pressure and the upper area of floating pressure equilibrium side-panel 5

and that of the pressure P_0 of lower internal friction cavity C and the lower area of floating pressure equilibrium side-panel 5 decreases the lower internal friction cavity gap δ and shifts down the loading pressure equilibrium side-panel 5 with the elastic supporting mechanism 2 overcome. Thus, the energy loss with the liquid flowing into the energy absorption device y has a cubic curvilinear add along with lower internal friction cavity gap δ reducing and increases linearly with the flow of liquid into the energy absorption device Q according to formula (1). All the energy losses are fully absorbed converting into heat energy and the value of the variable y is controlled by adjusting the lower internal friction cavity gap δ with regulating handle 11.

In the main energy absorption process, an algorithm model is established by experiments to calculate the energy loss with the liquid flowing into the energy absorption device.

$$y = f(\mu \frac{Q}{\delta^3}) \tag{1}$$

where:

y–the energy loss with the liquid flowing into the energy absorption device.

Q–the flow of liquid into the energy absorption device.

δ–lower internal friction cavity gap for the liquid flowing into the energy absorption device.

μ–the experimental coefficient related to the liquid medium.

(2) the control circuit: the value of lower internal friction cavity gap δ has corresponding changes according to the adjustment of the regulating handle 11. The regulating handle 11 is controlled by the output torque angle ω of the servo stepper motor 16. The input signal $\triangle I_3 \triangle U_3$ of the control computer 17 through the input control signal circuit 20 is obtained by the comparison of I_1U_1 and I_2U_2 with the potential difference comparator 18, which are the output signals from the signal conversion modules for pressure sensors in the upper plenum chamber 21 and the lower internal consumption cavity 22. Then the pulsing signals generated by the control computer 17 pass through the output pulse control signal circuit 19 to control the servo stepper motor 16. Thus, the regulating handle is adjusted by the servo stepper motor 16. The control process with analog variables can be divided into two parts: several regions are divided in the arithmetical or geometric series according to the magnitude of the absorption energy and then the value of the variable y is controlled. The different energy changes can be identified by the control computer 17 and the control programs according to analog signals are achieved. According to the different working conditions of the outside world, the program is adjusted by computer.

3.3 Characteristics and Innovation Points

Based on the hydraulic energy absorption device controlled with analog variables mentioned above, the patent for invention on high-power hydraulic emergency energy absorption device and method for the multistory parking area is authorized (ZL2013 1 0217678.0) [30]. The manual regulation hydraulic energy absorption device and method for emergency protection of the multistory parking area is patented for invention (ZL2013 1 0217657.9) [34], and the hydraulic energy absorption device controlled with analog variables is patented for utility models (ZL2013 2 0586602.0) [35]. And the characteristics and innovation points are as follows:

(1) The absorbed vibration energy is of large degree and the effect of vibration damping is good.
(2) The effect of vibration damping depends on Q proportionately, and it is inversely proportional to δ^3.
(3) The magnitude of the absorbed vibration energy is adjustable and controllable and the energy is stable and counteractive at vibration source. When external vibrational energy increases, the device absorbs more energy. The absorption energy fully matches with the vibrational energy and the value of the absorption energy can be controlled.
(4) The flat structure is adopted for good heat dissipation performance due to large heat dissipation area. As the lower inner friction cavity width L of the flow section is long, the whole system is of strong anti-interference ability even with localized flow channel blocked.

4 Conclusions

The self-tuning hydraulic vibration energy absorption device and method are suitable in applications of high speed, precision, light load and small or medium energy level. For example, the measurement accuracy is improved by vibration reduction with dynamic weighing in instrument. And the processing precision is achieved by vibration reduction for precision machine tools [2, 4, 18–22].

The invention patent of high power hydraulic emergency energy absorption for multi-story parking area is applicable to the conditions with high altitude fall, impact, collision and large-scale energy absorption, such as elevator emergency energy absorption safety devices, the bases of forging press machine tools, high-speed rail locomotive vehicle chassis, and so on [27].

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