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Researching on Valve System of Hydraulic Electromagnetic Energy-regenerative Shock Absorber

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Abstract: Hydraulic electromagnetic energy-regenerative shock absorber is a new kind of shock absorbers, who can perform the function of a standard shock while acting as an additional source of power. One of the core components of this new shock absorber is the valve system. And its function is to rectify the direction of the oil flow. Then the oil can flow through the hydraulic motor from one port only no matter in expansion stroke or compression stroke. The research focused on the compactness, sensitivity and energy recovery rate of two different valve systems. And the results showed that the valve system composed of check valves better matched the hydraulic electromagnetic energy-regenerative shock absorber.

Introduction

The function of automobile suspension is to transfer the whole force and torque between the wheels and the frame or the body, to ensure the vehicle ride and safety. And the duty of shock absorber of suspension is to attenuate the vibration of the frame or body, at the same time dissipating the energy. Twin tube shock absorber is a typical example of the shock absorber. Because of its low working pressure and stable performance, twin tube shock absorber is widely used. Unlike standard shock absorbers which dissipate energy by channeling fluid through orifices of a reciprocating piston, hydraulic electromagnetic energy-regenerative shock absorber routes fluid through a fluid circuit to recover the energy. Hydraulic electromagnetic energy-regenerative shock absorber uses a special valve system and a hydraulic motor coupled with an electric generator to provide damping and harvest otherwise wasted energy. Actually, Hydraulic electromagnetic energy-regenerative shock absorber performs the function of a standard shock while acting as an additional source of power.

1. The working principle of Hydraulic electromagnetic energy-regenerative shock absorber

The working principle of hydraulic electromagnetic energy-regenerative shock absorber shows in Fig. 1. It is a mechanical-electromagnetic-hydraulic coupling system, composed of hydraulic cylinder, tank, valve system, accumulator, hydraulic motor, generator, pipeline etc.. Its working process is that: At first, the piston of the hydraulic cylinder is drove to reciprocate under external excitation; Then, the oil flow through the valve system for rectification; thirdly, the oil flow through the accumulator for weakening fluctuations; finally, the continuously steady oil flow drives the hydraulic motor to generate electricity. In fact, the working process is also an energy conversion process. The reciprocating movement of the piston converts the external excitation into mechanical energy. The mechanical energy converts into kinetic energy of the fluid by the driving of the piston. Then, oil flow drives the motor and the motor drives the generator. The energy converts into electrical energy finally. What is important, the electrical energy can be stored in the battery for vehicle electronic equipment [1,2,3].

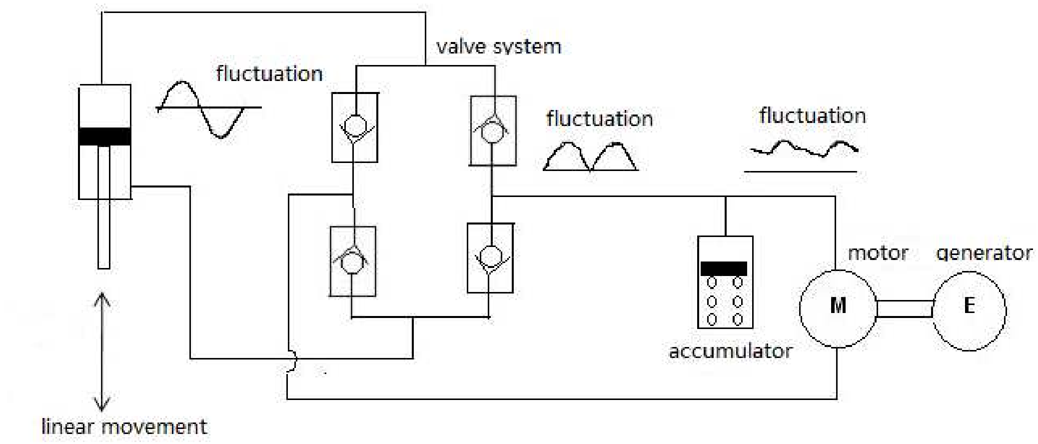


Fig. 1 The working principle of hydraulic electromagnetic energy-regenerative shock absorber

2. Researching on the valve system

The function of the valve system of the hydraulic electromagnetic energy-regenerative shock absorber is to rectify the direction of the oil flow. Then, the oil can flow through the hydraulic motor from one port only no matter in expansion stroke or compression stroke, enabling the motor work continuously. Eventually the generator can continuously to charge the battery. Thus, the researching on valve system for the energy recovery rate is essential. In addition to the function of rectifier, cooperating with power generation circuit, valve system will also help controlling the damping force of shock absorber, making the damping force greater in expansion stroke than compression stroke.

2.1 Valve system composed of the check valves

The oil flow is rectified by a group of check valves. Then, the oil will flow through the hydraulic motor from one port only. Namely, the hydraulic motor will not be reversed. For rectifier and meeting the dumping force, the parameters of each check valve such as cracking pressure, the maximum flow $Q_{\max}$, inlet diameter D, Pressure difference as the maximum flow ΔP need to select or design. Following, we can compute the preload force, maximum opening s, spring stiffness of each check valve.

In order to reduce the impact of temperature on the damping force, the general approach is to design the hole as the thin-walled hole. Then the Functional relation between the maximum flow and Pressure drop is that showed in Eq. 1, where C_q is the flow coefficient, ρ is the density of the hydraulic oil, A_0 is the opening area as maximum flow.

$$Q_{\max} = A_0 C_q \sqrt{\frac{2\Delta P}{\rho}} \tag{1}$$

Eq.1 has its application range: $\frac{s}{D} \le \frac{1}{4}$. When $\frac{s}{D} > 4$, the flow is inversely proportional to viscosity of the fluid. The relation between the damping force and the velocity of the piston can not maintain a relatively constant. Because the temperature greatly influents the viscosity. Therefore, we need to check out the relation between maximum open flow and inlet diameter after designing.

2.2 Valve system composed of slide valves

Valve system which is composed of slide valves is easier for assembly than valve system composed of check valves. Because a slide valve is equivalent to two check valves in function. The opening and closing condition of slide valve is that, they compare the pressure on both ends of the valve. High pressure side open, and low pressure side close. Its flow characteristics only relate with the diameter of the spool and the opening of the spool.

2.3 Comparative analysis of performance

Reliability and sensitivity of valve system directly impacts on the pressure and flow of the hydraulic circuit, thereby affecting the work of hydraulic motor and generator. Ultimately, it will affect the battery energy recovery. Therefore, the design of the valve system is critical.

Simulation analysis carried out on valve system consisted of check valves and slide valves according to automotive industry standards. Fig. 2 shows the relationship between outlet flow and time of the slide valve. It is easy to find out that valve system composed of slide valves have the phenomenon of periodic reverse flow from Fig. 2. And this phenomenon appears twice in each period. Through the analysis of the hydraulic circuit, we found reverse flow always appeared when the pressure in both upper and lower chambers of hydraulic cylinder was lower than the pressure in the accumulator. And this phenomenon caused by structural defect. So, it can not be eliminated.

However, valve system composed of check valves does not have the phenomenon of reverse flow. Because the opening and closing condition of check valve is that, they compare the pressure between upper and lower chamber of hydraulic cylinder and the accumulator. When the pressure of upper and lower chamber is lower than the pressure of accumulator, the check valve will not open. In addition, check valve has cracking pressure, which helps avoiding the reverse flow phenomenon. Fig. 3 shows flow character of check valve.

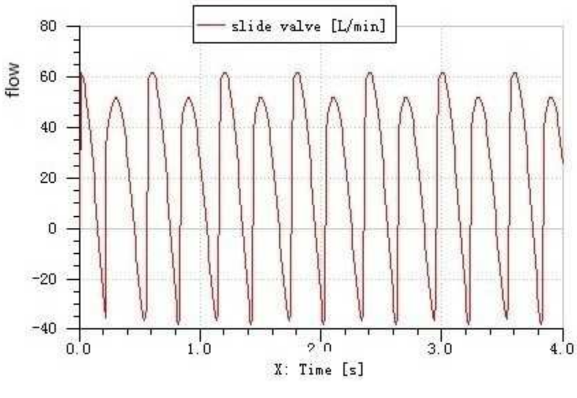


Fig. 2 Flow character of slide valve.

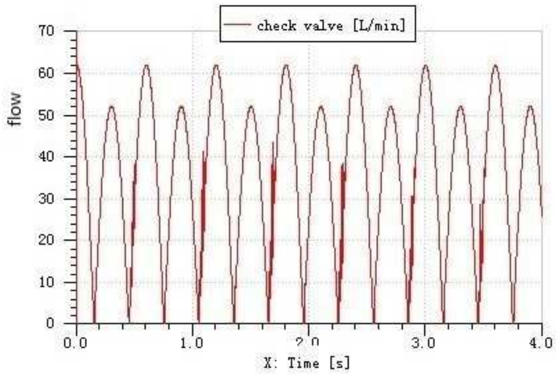
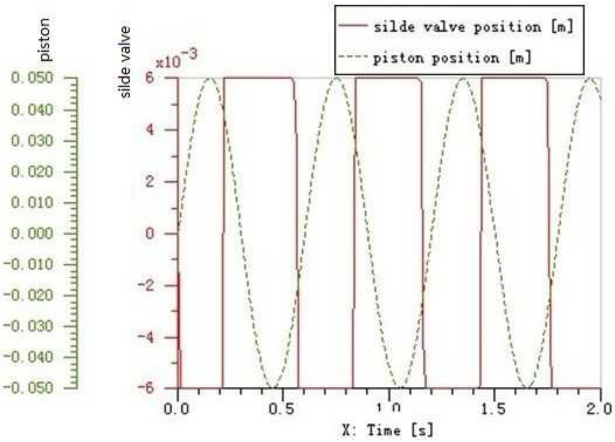


Fig. 3 Flow character of the check valve.

Meanwhile, the slide valve also has the opening and closing delay phenomenon which shows in Fig. 4. The red solid curve represents the position of the slide valve spool, while the green dashed curve represents the piston of the piston. From the picture it is easy to find out that whether opening or closing of the valve, the movement of the spool is delayed. And the delay time is 25% of the whole cycle time. The reason is that, the route of the valve is long, and the building process of pressure difference between upper and lower chamber need a few time. This phenomenon can be improved. But the improvement has limited extent, because the spool stroke is limited by the necessary flow.



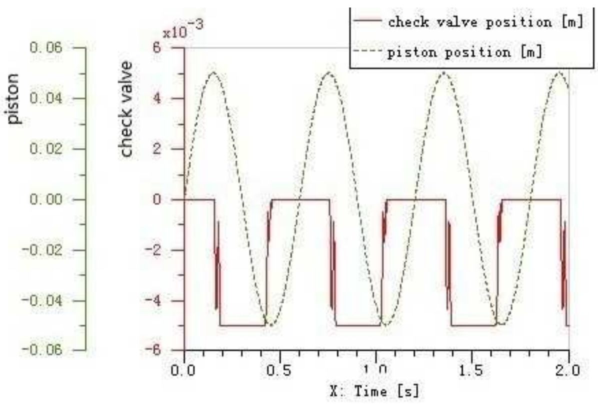


Fig. 4 Piston position, spool position VS time Fig. 5 Piston position, spool position VS time

Valve system composed of check valves has little delay. The main reason for possible delay is the cracking pressure of check valve and the pressure of the hydraulic system. Red solid curve in Fig. 5 represents the position spool, while the green dashed curve represents the position of the piston. It is easy to find out from the figure that the opening of the check valve has little delay, and the closing has a little early. These have proved that this valve system is sensitivity on any excitation.

3. Conclusion

The design of hydraulic electromagnetic energy-regenerative requires the shock absorber performing the function of a standard shock absorber. At the same time, maximizes energy recovery. And the process of energy recovery is a process of energy conversion. So, minimized energy loss is the target during the process of energy transfer. The essence of the reverse flow is that a few hydraulic oil flow back into the low pressure chamber directly without passing the hydraulic motor, which resulting in energy loss. What’s more, the valve system with the phenomenon of delay during opening and closing indicates that it is not sensitive to the emergence of energy, which can not quickly transfer the energy. Similarly, it will result in energy loss. Valve system composed of check valves can effectively reduce the energy loss by comparing the above two valve systems, although it is inferior to the valve system composed of slide valves in the structure compactness slightly. In short, valve system composed of check valves is a relatively ideal valve system.

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