Research on Nonlinear Characteristics of Bidirectional Adjustable Oil and Gas Suspension System And simulation analysis

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Abstract. This paper introduces the definition and working principle of bidirectional adjustable oil-gas suspension system. Through theoretical analysis, the nonlinear working characteristics of bidirectional adjustable oil-gas suspension system are qualitatively studied. The system model is built by AMESim hydraulic simulation software, and the influence on the system working characteristics is analyzed by adjusting structural parameters and working parameters.

1. Introduction
Oil and gas suspension system is widely used in modern engineering vehicles or special vehicles. This system can weaken the vibration caused by bumping into deceleration strips or uneven road surface excitation during the driving process of vehicles. The bi-directional adjustable oil-gas suspension system studied in this paper is a new type of suspension system developed independently, which can participate in the active adjustment of vehicle running state. Through theoretical analysis and simulation research, qualitative and systematic analysis of the working characteristics of the suspension system is of great significance to the improvement of the new suspension system and the guidance of production.

2. Introduction and working principle of bidirectional adjustable oil and gas suspension system
The bi-directional adjustable oil and gas suspension subsystem is assembled on the unmanned mobile platform to provide the platform with the main functions of shock absorption, shock resistance and active attitude control. The suspension system consists of one hydraulic station, four hydraulic power cylinders, eight pressure accumulators, four cable displacement sensors, eight accumulators, eight pressure transmitters, eight on-off valves, four groups of servo valves and several pipelines. There are four sets in the whole vehicle, which are respectively used to support the four sets of bridge arms, adjust the posture of the bridge arms and bear the impact from the wheels. As shown in the figure.
As shown in the figure, it is a schematic structural principle diagram of a bidirectional adjustable oil and gas suspension system mounted on an unmanned mobile platform. The body is equipped with four bidirectional adjustable oil and gas suspension systems, which independently control a corresponding rocker arm to adjust the body posture and play a role in shock absorption and impact resistance. A single bidirectional adjustable oil and gas suspension system mainly consists of a pressure accumulator, a power cylinder, a hydraulic control system, displacement and pressure sensors, etc. Wherein the power cylinder is taken as an executing element of the hydraulic system; The hydraulic control system realizes the oil charging and discharging control of the power cylinder and accumulator.

The hydraulic components used mainly include electromagnetic proportional valve, accumulator, power cylinder, proportional throttle valve, electromagnetic directional valve, electromagnetic stop valve, proportional overflow valve, hydraulic pump, etc. The electromagnetic proportional valve must have sufficient response speed to meet the oil charging and discharging requirements of the oil-gas spring under dynamic conditions. Hydraulic accumulators help absorb pressure fluctuations under dynamic regulation. The power cylinder shall have sufficient rigidity to meet the reliable transmission of hydraulic pressure. The proportional throttle valve is used to reduce the oil discharging speed of the accumulator. The displacement sensor monitors the position state of the power cylinder, the pressure sensor monitors the pressure of the accumulator and feeds back the data to the vehicle controller. The hydraulic system is controlled under the control and adjustment of the whole vehicle to realize the adjustment of the platform walking posture under dynamic and static conditions.
For the bidirectional adjustable oil and gas suspension system mounted on any bridge arm, the principle diagram is further simplified, and the working principle is explained as follows. When the valves C, A and F are closed and the valves D, B and E are opened, the high-pressure oil output by the hydraulic station enters the rod cavity of the hydraulic power cylinder, the bridge arm connecting rod is pulled, the bridge arm is driven to rotate to lift the round wheel, and the triangle wheel landing mode is realized; When the D, B and E valves are closed and the C, A and F valves are opened, high pressure oil enters the rodless cavity of the hydraulic power cylinder, pushes the bridge arm connecting rod, drives the bridge arm to rotate to make the round wheel land, and realizes the triangular wheel lifting mode. When the platform runs with four wheels on the ground, the C and D valves are closed, and the road surface undulation causes the bridge arm to swing, thus causing the piston rod to move left and right in the cylinder barrel. When the piston rod moves to the left, the nitrogen of the accumulator I is compressed to store energy, and the nitrogen of the accumulator II expands to release energy; When the piston rod moves to the right, the nitrogen of the accumulator I expands to release energy, and the nitrogen of the accumulator II is compressed to store energy, thus achieving the effect of energy absorption and shock absorption. When the valves C, A, F and E are closed and the valves D and B are opened, the proportional relief valve in the hydraulic system is utilized to automatically adjust the magnitude of the overflow pressure, change the amount of gas compression in the accumulator, and realize the adjustment of the buffering rigidity of the platform. At the same time, the proportional relief valve can also ensure that the accumulator always has hydraulic energy under any conditions, and the phenomena of air suction, cavitation and the like in the cylinder cannot be formed during buffering, thus improving the stability of the system and the service life of the power cylinder and hydraulic oil. On special ground, such as when the platform crosses trenches, the platform needs to lose its vibration damping function. The electromagnetic cut-off valve can be energized, and the platform can obtain sufficient rigidity, which is beneficial for the platform to cross wider trenches. Selecting a constant power electric proportional variable pump can automatically reduce the output speed of the hydraulic system when the external load increases, maintain an ideal working state, and increase the application range of the platform.

3. Theoretical Analysis of Nonlinear Characteristics

![Fig. 3 Schematic structural diagram of dynamic analysis on the working principle of rocker and power cylinder](image)

Taking the power cylinder as the research object, during the rotation of the power cylinder, Resistance moment is: 
\[ M_z = m_5 g \times \left( \frac{M}{2} \right) \times \cos \theta \]
The power distance is:

\[ M_d = F \times \cos \alpha \times M = F \times \cos \alpha \times (L_0 - \omega \times s \times \sin \alpha \times t) \]

\[ M_d - M_s = J_\alpha \cdot \tau \cdot \cos \alpha \]

Among them, \( M_d \) is the power moment applied to the power cylinder, \( M_s \) is the resistance moment applied to the power cylinder, \( J_\alpha \) is the rotational inertia of the power cylinder, and \( \tau \) is the rotational angular acceleration of the rocker.

\[ F \cdot \cos \alpha \cdot (L_0 - \omega \cdot s \cdot \sin \alpha \cdot t) - m_y \cdot g \cdot S \cdot \cos \alpha = \frac{1}{3} m_y \cdot S^2 \cdot \tau \]

Take the rocker as the research object: \( F \cdot \cos \alpha = -F' \cdot \cos \alpha \)

\[ M_c = m_y \cdot g \cdot \frac{S}{2} + F' \cdot \cos \alpha \cdot s \cdot \cos \alpha = \frac{1}{3} m_y \cdot S^2 \cdot \tau \]

Among them, \( M_c \) is the road impact moment transmitted by the rocker arm on the rocker arm.

By combining the above equations:

\[ \frac{M_c - m_y \cdot g \cdot \frac{S}{2} - F' \cdot \cos \alpha \cdot s \cdot \cos \alpha}{\frac{1}{3} m_y \cdot S^2} = \frac{F \cdot \cos \alpha \cdot M - m_y \cdot g \cdot \frac{M}{2} \cdot \cos \theta}{\frac{1}{3} m_y \cdot M^2 \cdot \cos \alpha} \]

\[ \frac{M_c - F \cdot \cos \alpha \cdot m_y \cdot \frac{g}{2} \cdot m_1 \cdot \frac{1}{2} \cdot \cos \theta}{m_y \cdot s^2} = \frac{F \cdot \cos \alpha - m_y \cdot g \cdot \frac{1}{2} \cdot \cos \theta}{m_y \cdot \frac{1}{2} \cdot \cos \theta} \]

\( M = L_0 - \omega \cdot s \cdot \sin \alpha \cdot t \)

That is: The relationship between the impact torque \( M_c \) with the included angle \( \alpha \) of the rocker power cylinder and the rotation angle of the power cylinder \( \theta \) is obtained.

Simulate the working state of each component of the system during a slow compression process of the piston rod of the power cylinder, and use matlab software to draw the relationship curves between the key parameters to help analyze and observe the nonlinear working characteristics of the system. Known rocker power cylinder working process related parameters are shown in the following table.

| Table 1. Structure or Working Parameters of Rocker and Power Cylinder |
|-------------------------------------------------|
| Name of structure or working parameter | Parameter value |
|------------------------------- |----------------|
| Rocker length s | 30mm |
| Original length of power cylinder L0 | 500mm |
| Rotational angular velocity | 1rad/s |
| Power cylinder mass | 20kg |
| Rocker mass | 4kg |
| Gravity acceleration g | 10m/s² |
| Working time t value range | [0:0.02:0.65]s |

Since it is a slow compression process, the angular acceleration of rocker rotation is 0. It may be assumed that the included angle of the rocker power cylinder is equal to the working time \( T \) during rotation. The relationship between the power cylinder length \( M \) and the time \( T \), the relationship between the power cylinder rotation angle and the time \( T \), the relationship between the impact force \( F \) and the time \( T \), and the relationship between the power cylinder length \( M \) and the rotation angle as well as the relationship between the impact force \( F \) and the rotation angle of the power cylinder can be found respectively. At the same time, the relationship curve between the impact moment and the time...
T can be found by using the relationship formula of the impact moment in the dynamic mathematical model. The correlation curve is shown in the following figure:

(a) Curve of power cylinder length versus time
(b) Curve of Relationship between Rotation Angle and Time of Power Cylinder
(c) Relation curve between force and time of piston rod of power cylinder
(d) Relation curve between power cylinder length and rotation angle
(e) Curve of power cylinder length versus time
(f) Curve of Relationship between Rotation Angle and Time of Power Cylinder

Fig. 4 Nonlinear operating characteristics of rocker and power cylinder model
From the kinematics and dynamics mathematical model of the rocker power cylinder, it can be seen that in the design process of the oil-gas suspension subsystem of the rocker power cylinder, the structural parameters such as the diameter, length, weight, stroke of the piston rod, length, weight of the rocker, installation position relation of the two structures, initial working position, etc. play a vital role in the working state of the system. In the process of studying the passive response characteristics of the bidirectional adjustable oil-gas suspension system, the establishment of the kinematics and dynamics mathematical model of the rocker power cylinder can help analyze the relationship between the structural parameters and the working parameters during the working process, which is of great significance to the structural design and the characteristic research.

4. Model Simulation of Bidirectional Adjustable Oil and Gas Suspension System Based on AMESim

In AMESim, the bidirectional adjustable oil and gas suspension system model is built. The main components of the model include a one-way quantitative hydraulic pump controlled by a motor, a proportional overflow valve, a three-position four-way valve, a hydraulic lock, an electromagnetic valve, a pressure accumulator, a single-acting single-piston cylinder, a power cylinder excitation signal and a control system. In the model, three-position four-way valve and other electro-hydraulic servo valves are used as bridges to connect electrical signals and hydraulic signals. The electro-hydraulic servo valves are not only electro-hydraulic conversion components but also power amplification components of the whole system, and are the core components of the electro-hydraulic servo system. The three-position four-way valve plus the two-way hydraulic lock functions as the C and D valves in the principle diagram. The opening size and rated flow rate of the valve are taken as the main working parameters of the valve.

![Fig. 5 Establishment of AMESim simulation model of bidirectional adjustable oil and gas suspension system](image)

Set the key parameters of each working component in the established bidirectional adjustable oil and gas suspension system model, as shown in the following table.
Table. 2 Setting of Working Parameters of Main Components of Bidirectional Adjustable Oil and Gas Suspension System

| Parameter name               | description                                           | description     |
|------------------------------|-------------------------------------------------------|-----------------|
| Oil                          | The power cylinder has the peak value of impact force in the compression process of rod end. | 150KN           |
| Oil flow coefficient         |                                                       | 0.7             |
| Oil density                  |                                                       | 0.86g/cm³       |
| Accumulator gas              | Gas polytropic index                                  | Normal nitrogen |
| Initial inflation volume     |                                                       | 3L              |
| Initial inflation pressure connected with rod end | 8MPa         |                 |
| Connect the initial inflation pressure at the rodless end. | 4MPa         |                 |
| Cylinder diameter            |                                                       | 75mm            |
| Trip                         |                                                       | 272mm           |
| Power cylinder               |                                                       |                 |
| Inner-diameter               |                                                       | 64mm            |
| Outer diameter of piston rod |                                                       | 40mm            |
| Trip                         |                                                       | 450mm           |
| Hydraulic station            |                                                       |                 |
| Pressure                     |                                                       | ≤9MPa           |
| Traffic                      |                                                       | 15L/min         |
| Motor power                  |                                                       | 4.5KW           |
| Servo valve                  |                                                       |                 |
| Angle control precision pressure | ≤0.25°   |                 |
| Piston rod                   |                                                       |                 |
| Attack time                  |                                                       | 0.4s            |

Fig. 6 Operating characteristic curve of suspension system during static drop
5. Conclusion

Through the analysis of the working principle of the oil-gas suspension system and the dynamic analysis of the bridge arm power cylinder module of its main working structure, the non-linear relationship between the length, angle, force and time of the power cylinder push rod is obtained. The non-linear working characteristics of the system are studied by comparing the relationship between the parameters. The AMESim system simulation model is established to simulate the passive adjustment of all working components of the suspension system during the static drop of the vehicle body. In addition, the expansion and contraction of the power cylinder push rod of the suspension system and the rigidity adjustment during driving can be realized by adjusting the opening and closing of the electromagnetic valve in the simulation model. The article includes theoretical analysis and the establishment of simulation model, which has important guiding significance for the design and improvement of special vehicle oil and gas suspension system.

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