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Optimized Design and Simulation of Working Arm Hydraulic System for High Efficiency Environmental Protection Equipment

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Abstract: Aiming at the shaking phenomenon during the working process of a high-efficiency environmental protection equipment working arm hydraulic system, taking the hydraulic system controlling the lifting action of the working arm as the research object, analyzing the reasons for the phenomenon, and carrying out the optimization design and simulation research of the anti-shaking hydraulic system. The research results show that: the working arm anti-shaking hydraulic system through the one-way throttle valve return back pressure and a reasonable choice of the balance valve pilot ratio, improve the flow matching degree of the balance valve, reduce its switching frequency, can significantly improve the stability of the working arm descending system, anti-shaking design effect is obvious. The results of the research on the optimization of special equipment hydraulic system design are of great significance.

Keywords: Working Arm; Shaking; Design and Simulation; Balance Valve; Optimization.

1. Introduction

In recent years, with the rapid development of the automobile industry, the global automobile ownership is also increasing rapidly. According to data released by China's National Bureau of Statistics, the country's civilian car ownership exceeded 330 million at the end of 2023, an increase of 17.14 million from the end of the previous year. At the same time, according to the calculation that the scrapping life of automobile is about 15 years, it is expected that the number of scrapped automobiles in China will reach 22 million in 2025 [1]. While the number of end-of-life vehicles is increasing, the corresponding environmental protection equipment technology is developing rapidly; among them, the end-of-life vehicle dismantling machine, which replaces the manual dismantling operation, is a kind of high-efficiency environmental protection equipment, which can effectively liberate the hands of the workers, and greatly improve the dismantling efficiency, and the market demand has a huge prospect.

At present, foreign scholars and researchers have carried out many researches around the research and development of dismantling equipment for end-of-life automobiles, process and system optimization, and have made remarkable achievements [2-4]; while the domestic dismantling and recycling industry of end-of-life automobiles started late, and the development of environmentally friendly dismantling equipment for automobiles is almost in a blank state, and the backward dismantling methods and primitive dismantling means directly lead to the waste of resources and a high degree of pollution of the environment. As a crucial link in the dismantling of end-of-life automobiles, dismantling equipment technology has increasingly become the focus of attention in the industry [5-9].

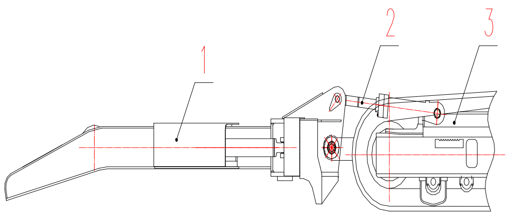
Article for a certain model of scrap car dismantling machine working arm down in the process of shaking and stall phenomenon, to control its lifting hydraulic system as the object, from the overall viewpoint of the hydraulic system of the whole machine, its hydraulic system optimization design and simulation research. Through the combination of theoretical analysis and simulation, we analyze the performance of the main components and their influencing factors, which is of great theoretical and practical significance for the development and optimization of the hydraulic system of special equipment.

2. Basic Structure of Working Arm

1-Scrap car dismantler 2-Boom 3-Arm 4-Hydraulic clamp 5-Working arm

Fig 1. Scrap car dismantler of a certain type

Scrap car dismantling machine is a new type of environmental protection equipment improved on the basis of hydraulic excavator, utilizing its flexible and strong dismantling pliers for cracking and dismantling scrap cars; at the same time, in order to guarantee the dismantling efficiency, it is often necessary to use the working arm to fix the scrap car. Figure 1 shows a certain model of scrap car dismantling machine, mainly including: movable arm, bucket bar, dismantling shears and working arm working arm.



1-Working arm 2-Control cylinders 3-Lower body

Fig 2. Working arm structure sketch

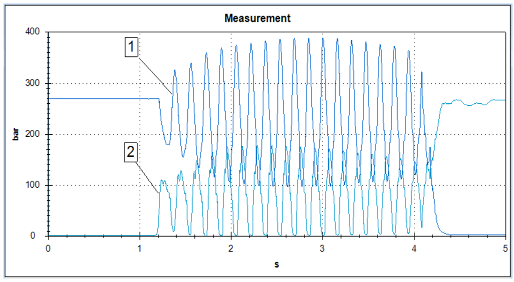
Figure 2 is a sketch of the structure of the working arm of the scrap car dismantling machine, whose main components include the working arm 1, the working arm cylinder 2, and the lower arm 3, which is hinged to the lower arm of the machine, the lower arm main frame adopts the double-supporting work-type beam structure, and the root part of the movable arm adopts the double-supporting structure, so that the platform load-bearing capacity and the structural strength are significantly improved, and the assembling process performance is better. The working arm is a multifunctional adjustable clamping arm with up and down, left and right degrees of freedom.

When carrying out dismantling operation, the driver controls the dismantling machine's large and small arm cylinders, the machine's slewing motor, the hydraulic clamp cylinder and its motor to carry out composite action through the operating handle, adjusts the dismantling position and angle of the hydraulic clamp, and selects the best dismantling point to carry out dismantling operation. For the characteristics of dismantling operation, in order to improve the efficiency of dismantling operation, the working arm shown in Figure 2 is usually used to fix the position of the dismantled object, which can realize the operation of pressure, top, pulling, cutting and peeling with the use of hydraulic tongs; the left and right opening and closing of the working arm is controlled by a pair of double-acting hydraulic cylinders, and the internal bowl-type fixture can fix the automobile wheel hubs and other small objects, and the internal wedge fixture can be used to dismantle the particularly strong objects. The top of the assembly of a variety of steel teeth can realize cutting, bending, curling, exploitation and other functions. Among them: when the rodless chamber of the working arm cylinder feeds oil and the rod chamber returns oil, the working arm descends; on the contrary, the working arm rises.

3. Design of Anti-shaking Hydraulic System for Working Arm

3.1. Schematic Design

At the beginning of the system design, in order to reduce the system heat, the hydraulic system circuit of the working arm only adopts the balancing valve to control the hydraulic cylinder of the working arm lifting and lowering action, but in the actual installation of the test run, it is found that there is a more serious phenomenon of the working arm shaking, which affects the coordination of the dismantling operation and high efficiency. Through the Renault CHPM 8-channel hydraulic test equipment to test the working arm when descending, the hydraulic cylinder controlling the lifting and lowering action of the working arm has a rod chamber and rodless chamber pressure curve shown in Figure 3:

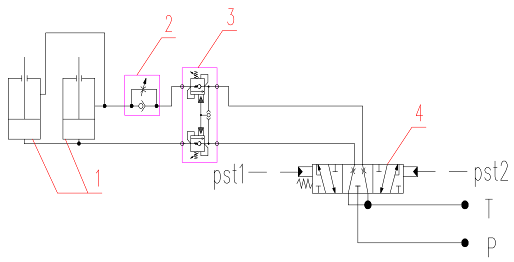


1 - Rodless chamber pressure 2 - Rodded chamber pressure

Fig 3. Pressure curve of working arm lifting hydraulic cylinder

In view of the above phenomenon, analyze the working arm action characteristics, found that the working arm for the self-weight of the larger welding structural components, in its descent, with the control of the working arm lifting action of the hydraulic cylinder extends to cause its center of mass change faster, resulting in a large rate of change of the load of the hydraulic system. Higher load change frequency of the hydraulic system causes the balance valve to open and close repeatedly, and the flow rate is poorly matched, which manifests itself as obvious shaking of the whole working arm, affecting the stability of the whole machine.

Since the main structure of the dismantling machine and the hydraulic system have been completed, the solution to the above shaking phenomenon needs to follow the principle of not making large changes to the hydraulic system hardware or the whole machine mechanism. According to the above analysis, the article designed a working arm anti-shaking hydraulic system. Different from the initial design of the working arm hydraulic system, the anti-shaking hydraulic system in the hydraulic cylinder rod chamber and the balance valve between the addition of a one-way throttle valve, in the working arm down on the system to provide a stable back pressure, control the rate of change of its center of gravity, and effectively match the flow of the system, so as to make its descent more smoothly. The principle is shown in Figure 4:



1-Working Arm Cylinder 2-Check Throttle Valve 3-Balance Valve Unit 4-Multi-way Valve

Fig 4. Schematic diagram of working arm anti-shaking hydraulic system

3.2. Main Component Parameters

3.2.1. One-way Throttle Valve

By analyzing the principle, it can be seen that the one-way throttle valve on the balance valve control role is mainly in the working arm down condition, in order to study the influence of the one-way throttle valve on the balance valve. One-way throttle valve throttle spool flow continuity equation is as follows [5]:

$$Q_b = C_d A \sqrt{\frac{2(p_A - p_B)}{\rho}} \quad (1)$$

Where: Qb is the flow through the throttle valve; A is the throttle valve flow area; C_d is the flow coefficient; ρ is the density of hydraulic fluid; P_A P_B is the throttle valve; A B is the port pressure.

3.2.2. Balancing Valve

Pilot ratio as an important parameter in the selection of balancing valve, which is defined as: the ratio of pilot area and relief area, is the ratio of the pilot pressure value when the balancing valve spring is set at a fixed value, the balancing valve in the pilot pressure oil is 0, the reverse opening pressure value and the pilot pressure value when there is a pilot pressure oil balancing valve reverse opening [6-7]. The expression is as follows:

$$R = \frac{A_P}{A_r} \quad (2)$$

The opening condition of the liquid-controlled throttling function of the balancing valve is:

$$P_B \cdot R + P_A > p_S \quad (3)$$

When the balancing valve acts on the cylinder rod cavity chamber, the piston force balance equation is:

$$P_B \cdot S_1 + F = P_A \cdot S_2 \quad (4)$$

Then:

$$P_A = \frac{F}{S_2} + P_B \cdot \frac{S_1}{S_2} = P_L + P_B \cdot \varphi \quad (5)$$

According to the critical equilibrium condition, it can be derived:

$$P_B = \frac{P_S - P_L}{R + \phi} \quad (6)$$

Similarly, when the balance valve acts on the rodless cavity:

$$P_B = \frac{P_S - P_L}{R + \frac{1}{\phi}} \quad (7)$$

Where: A_p is the pilot area; A_r is the relief area; P_s is the balancing valve set pressure; P_A is the load pressure; P_B is the control pressure; S_1 is the rodless cavity effective area of action; S_2 is the rod cavity effective area of action; F is the piston rod load force; φ is the hydraulic cylinder speed ratio; R is the balancing valve pilot ratio.

Through the analysis of the mathematical model of the above main components, we can find the main parameters affecting the dynamic characteristics of the one-way throttle valve and the balancing valve, which can improve the corresponding output pressure characteristics and improve the stability of the system through reasonable matching.

Other major component parameter settings are shown in Table 1:

Table 1. Main parameters of hydraulic system

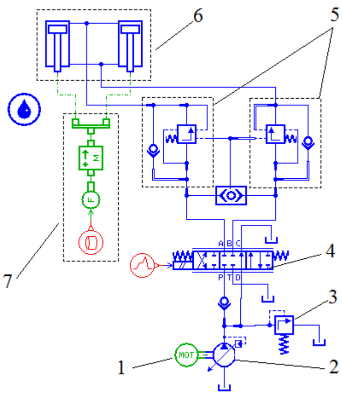
Parameter name	Units	value
Variable Pump Displacement	ml/r	30
Engine speed	r/min	2200
Directional Valve Flow Rating	L/min	60
Check Throttle Rated Flow	L/min	60
Maximum opening pressure of balance valve	MPa	35
Balance Valve Rated Flow	L/min	60
Balance valve pilot ratio	-	2.6
Hydraulic cylinder diameter ratio	-	50/28

4. Modeling and Simulation Analysis of Anti-Shaking Hydraulic System of Working Arm

Considering the actual situation, the model load using the dynamic schedule module in the signal library, imported into the collection of the load change fitting data; reversing action of the reversing valve is set directly by the segmented linear signal source in the signal library. In order to improve the model simulation calculation efficiency, on the basis of not affecting the system characteristics, the simulation model of some hydraulic components is simplified as necessary, and other components are set according to the actual parameters [8].

4.1. Original System Modelling and Simulation

In order to qualitatively study the hydraulic system of the working arm and verify the correctness of the simulation model establishment, according to the previous analysis, the AMESim simulation model of the original hydraulic system shown in Fig. 4 is established, and the original hydraulic system of the working arm is simulated and analysed during the descending action.



1-Engine 2-Variable displacement pump 3-Safety valve 4-Direction valve 5-Balance valve set 6-Working arm lift cylinder set 7-Load

Fig 5. Simulation model of the original working arm hydraulic system

Simulation results as shown in Figure 6, the original hydraulic system of the working arm there are more dramatic pressure fluctuations. Comparison of Figure 3 found that: the system pressure simulation results and test results in terms of the size of the value, the trend of change are very close to the test results, which exists part of the difference is due to the test when the driver operated the handle start too quickly, while the simulation of the control signal is a smooth curve, the start-up phase of the pressure amplitude of the relatively small, in line with the characteristics of its action. Therefore, the simulation model is established correctly.

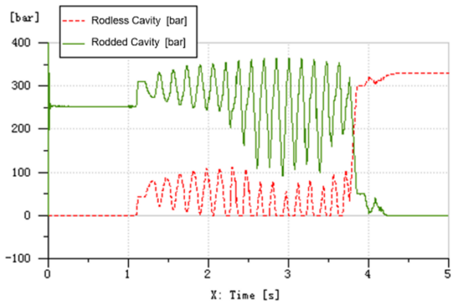
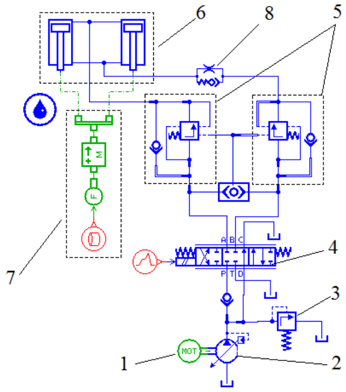


Fig 6. Pressure curve of working arm lifting cylinder of the original system

4.2. Modelling and Simulation of Anti-shudder Hydraulic System

According to the design principle of Figure. 4, the AMESim simulation modelling of the working arm anti-shaking hydraulic system shown in Figure. 7 is established to simulate and analyse the descending action of the working arm anti-shaking hydraulic system.



1-Engine 2-Variable pump 3-Safety valve 4-Directional valve 5-Balance valve group 6-Check throttle valve 7-Load 8-Working arm lifting cylinder group

Fig 7. Simulation model of working arm anti-shaking hydraulic system

4.3. Simulation Results

Figure 8 is the anti-shaking system working arm lifting cylinder pressure curve, found that the working arm anti-shaking hydraulic system in the working arm down, its working cylinder cavity still exists a certain pressure fluctuations, but compared with the original system pressure fluctuations reduced significantly, in which the cylinder rod cavity amplitude is reduced significantly, amplitude reduction of up to 21.5%; as a result of the use of a one-way throttle valve, the rodless cavity return oil is blocked, the formation of the system backpressure, reduce the Balance valve switching rate, resulting in the average pressure of the rodless cavity is larger than the original system, but the pressure is smoother; due to the working arm cylinders do not have a higher speed requirements, and less flow, the system uses a one-way throttle valve, the heating of the entire hydraulic system does not have an impact on the operating requirements, so this design is feasible.

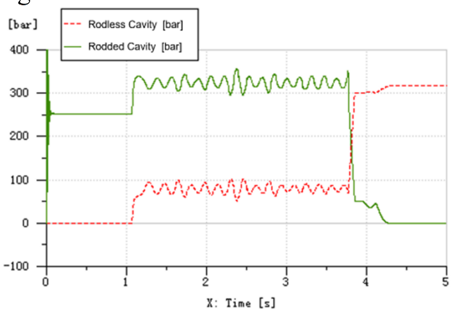


Fig 8. Pressure curve of working arm lifting cylinder of anti-shaking systems

Figure 9 is the pressure curve of lifting cylinder under different pilot ratio of balance valve, and it is found that the working arm anti-shaking hydraulic system in the lowering of the working arm, due to the use of three different pilot ratio balance valves, there are three kinds of pressure fluctuations of the working cylinder cavity with the same trend and different values, which reduces the pressure fluctuation significantly compared with the original system. Among them, when the pilot ratio of the counterbalance valve R=2.6, the amplitude of the cylinder rod cavity is reduced significantly, reaching 23.5%; due to the different pilot ratios of the counterbalance valve, it means that the back pressure of its system return oil is different, which results in the difference of the switching frequency of the counterbalance valve, which is ultimately manifested in the difference of the pressure fluctuation values. According to the working characteristics of the counterbalance valve, its switching frequency can not be too high or too low, need to meet the working requirements of the case of reasonable choice. Therefore, this paper selected the counterbalance valve pilot ratio of 2.6 is more appropriate.

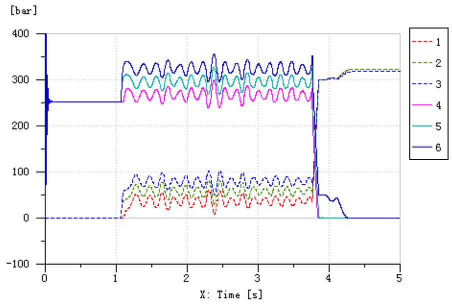


Fig 9. Pressure curves of lifting cylinders under different pilot ratios of balancing valves

1-3 Pressure in rodless chamber with pilot ratio R of 3.0 2.6 2.0 4-6 Pressure in rodless chamber with pilot ratio R of 3.0 2.6 2.0

5. Conclusion

(1) The anti-shuddering hydraulic system reduces the pressure fluctuation significantly compared with the original system, and the amplitude of the rod cavity of the cylinder can be reduced up to 21.5%; due to the use of a one-way throttle valve, the oil return to the rodless cavity of the cylinder is blocked, which forms the back pressure of the system and reduces the switching rate of the counterbalance valve, which results in the average pressure of the rodless cavity being larger than that of the original system, but the pressure is smoother.

(2) The difference in the pilot ratio of the counterbalance valve leads to the difference in the switching frequency of the counterbalance valve, which is ultimately manifested in the different values of pressure fluctuation; when the pilot ratio of the counterbalance valve R=2.6, the amplitude of the rod cavity of the cylinder is reduced significantly, reaching 23.5%.

(3) The anti-shaking hydraulic system of the working arm improves the flow matching degree of the counterbalance valve and reduces its switching frequency through the back pressure of the one-way throttle valve and the reasonable selection of the pilot ratio of the counterbalance valve, and the system optimization effect is obvious.

Acknowledgments

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