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Control Algorithm of Electro-hydraulic Braking System

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Abstract

In allusion to short pressure maintaining time, slow response and poor practicability of control algorithm in the current electro-hydraulic active braking system, one improved system and its control algorithm are proposed. Two normally closed boost valves, pressure reduction valves and self-locking magnetic valves are added in the double pipeline between the master cylinder and ABS or ESP, respectively, and the shuttle valve is cancelled, so that the system retains the double pipeline safety design, realizes power-off and pressure maintenance, and ensures the effectiveness of the system in the manual braking mode. The response time of the system is shortened by high-pressure energy storage, two-way pressurization and pre braking. The double closed-loop control based on distance and deceleration is adopted to improve the practicability of the control algorithm. The system can maintain pressure for any long time and respond quickly. The control algorithm not only ensures the smoothness of braking, but also improves the driving safety.

Keywords

Electro-hydraulic brake; control algorithm.

1. Introduction

In allusion to the shortcomings of the current electro-hydraulic active braking scheme and control algorithm, an improved electro-hydraulic active braking system and control algorithm are proposed, which retains the original dual pipeline safety design, replaces the original normally open pressure reducing valve with the normally closed pressure reducing valve, and adds the self-locking solenoid valve to achieve pressure maintaining at any time. In the part of control algorithm, pre braking is introduced, which combines two-way pressurization and high-pressure accumulator to shorten the response time of system pressure building and deceleration. Through the double closed-loop minimum safe following distance control algorithm based on distance and deceleration, the smoothness, driving safety and road driving efficiency of braking are guaranteed.

2. General Electro-hydraulic Active Braking System

A shuttle valve is added to the two-way hydraulic pipeline between the original hydraulic brake master cylinder and ABS or ESP. moreover, one or two-way hydraulic pressure boosting devices are connected in parallel to realize active braking. This scheme can realize automatic switching between manual braking and active braking modes through the shuttle valve. When working in the active braking mode, the shuttle valve slides to the end of the brake main cylinder pipe of the original vehicle under the pressure of the active boosting pipeline. The normally closed booster valve and normally open pressure reducing valve are connected with the double input pipeline of the ABS or ESP of the original vehicle through the shuttle valve. When working in

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the manual brake mode, the shuttle valve slides to the end of the active booster pipe under the hydraulic pressure of the brake master cylinder. The brake master cylinder is connected with the ABS or ESP double input pipe of the original vehicle. The oil in the slave cylinder directly enters the ABS or ESP pipe under the action of manual and vacuum assistance to realize the manual brake. The typical structure and principle are shown in Fig.1. The original ABS / ESC function of the hydraulic braking system is retained, and only the active boosting and pressure regulating parts need to be developed, so the engineering application development is difficult. The hydraulic booster part is driven by a DC brush less motor to drive the hydraulic oil pump to pump the brake fluid from the master cylinder (or oil tank) to the high-pressure accumulator, and the check valve connected in the middle is used to prevent the fluid from flowing back. In order to shorten the braking response time, the system needs to pre build the pressure to ensure that the hydraulic pressure in the accumulator maintains a certain pressure. The hydraulic pressure sensor is used for the hydraulic pressure feedback. Moreover, the overflow valve can also control the hydraulic pressure within a certain range to prevent the overpressure damage or excessive pressure from causing the oil leakage. The pressure regulating part is mainly composed of two high-speed on-off valves, the booster valve is a normally closed high-speed on-off valve, the pressure reducing valve is a normally open high-speed on-off valve, the booster valve is connected with the pressure source and the pressure output pipeline, and the pressure reducing valve is connected with the pressure output pipeline and the oil tank. The boost and pressure reducing valves are controlled by PWM, and the opening time of the valve is regulated by adjusting the duty cycle of PWM. When it is necessary to pressurize, increase the opening time of the pressurization valve; when it is necessary to depressurize, increase the opening time of the pressure relief valve. The output pressure can be adjusted and controlled by controlling the opening time of the pressure increasing valve and the pressure reducing valve.

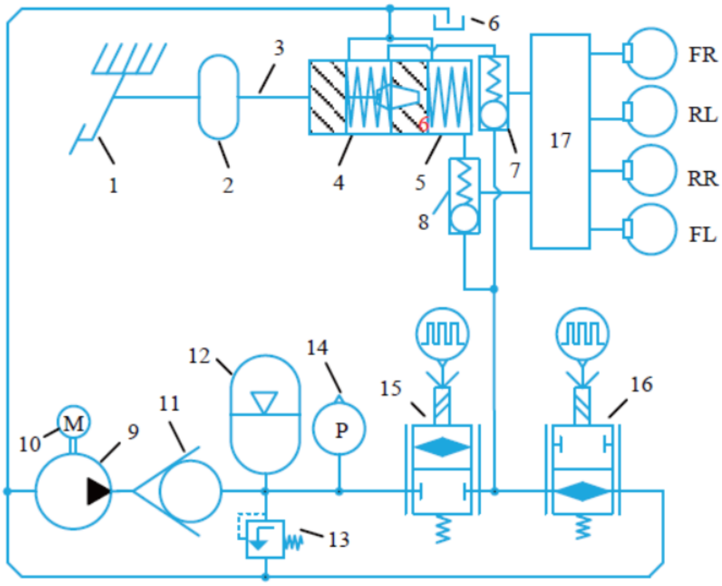

Fig 1. Structure of electro-hydraulic active braking system

(1. brake pedal, 2. vacuum booster, 3. push rod of master cylinder, 4. brake master cylinder, 5. piston of master cylinder, 6. oil pot, 7. 8. shuttle valve, 9. hydraulic pump, 10. Motor, 11. check valve, 12. high pressure accumulator, 13. overflow valve, 14. hydraulic pressure sensor 15,. normally closed booster valve, 16. normally open pressure reducing valve, 17. ABS/ESP)

When the active brake is in the supercharging stage, the normally closed supercharging valve opens, the normally open pressure reducing valve closes, and the pressure source generated by the hydraulic pump enters the ABS or ESP double input pipe through the supercharging valve to realize the supercharging. When the active brake is in the pressure reducing stage, the normally closed booster valve is closed and the normally open pressure reducing valve is opened, so that the pipeline oil can be returned to the main cylinder through the normally open pressure reducing valve for pressure reduction. During the pressure reducing process, the opening time of the normally open valve can be adjusted by adjusting the PWM duty ratio of the normally open valve. When pressure maintaining is required, the normally closed booster valve is closed, the normally open pressure reducing valve is closed, and the two normally open valves are closed to maintain the pipeline pressure.

This scheme is aimed at the research institutions, vehicle enterprises and IT enterprises engaged in the research and development of ADAS system and intelligent vehicle. When they do not have the ability of ABS or ESP development or do not plan to invest funds to redevelop the brake system, the original vehicle's ABS or ESP system is retained, and the electronic hydraulic supercharger is connected in parallel or in series on the double input pipeline between the brake master cylinder and ABS or ESP to realize the electric by wire control. The hydraulic active braking is an optimal scheme. It can provide two modes of active braking and manual braking, but it also has the following disadvantages: (1) ABS/ESP dual pipeline shares one pressurization pipeline, one pressurization valve will cause the pipeline pressure build-up and decompression time to be prolonged, and also destroy the independent safety design of the two pipelines during active braking. (2) There is a risk that the ball position cannot be predicted when the shuttle valve leaks oil or reduces pressure. (3) The normally open pressure reducing valve can ensure the complete release of brake wheel cylinder hydraulic pressure and the effectiveness of manual braking after the brake is completed, but in the active braking mode, the normally open pressure reducing valve needs to be energized to maintain the pressure, if it needs to maintain the pressure for a long time, it will cause the electromagnetic valve to overheat and burn out, cannot meet the long-term braking demand under extreme conditions.

3. Improved Electro-hydraulic Active Braking System

Based on the current parallel electro-hydraulic active braking system (Fig.1), an improved electro-hydraulic active braking scheme is proposed. The system structure and working principle of this scheme are shown in Fig.2.

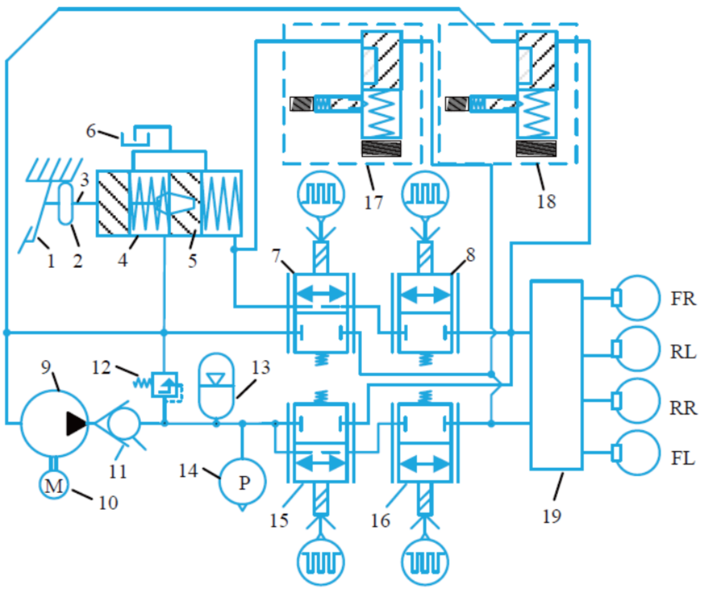

Fig 2. Structure of improved electro-hydraulic active braking system

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1. brake pedal, 2. vacuum booster, 3. push rod of master cylinder, 4. brake master cylinder, 5. piston of master cylinder, 6. oil pot, 7. 8. normally closed high-speed switch pressure reducing valve, 9. hydraulic pump, 10. Motor, 11. check valve, 12. overflow valve, 13. high pressure accumulator, 14. hydraulic pressure sensor, 15, 16. normally closed high-speed switch booster valve, 17, 18. self-locking solenoid valve 19. ABS / ESP

In view of the problems in the scheme shown in Figure 1, the following improvements have been made: (1) In order to keep the original ABS or ESP two-way independent safety design, in addition, two-way normally closed high-speed switch boost valve and two-way normally closed high-speed switch relief valve have been added to ensure the independence of the ABS or ESP two-way input pipeline, and at the same time, the pipeline pressure building time has been shortened. In order to further shorten the pressure build-up time, the high-pressure accumulator is reserved. (2) The shuttle valve is cancelled. When the active brake fails or the manual brake is applied, the additional two-way normally closed pressure reducing valve can be energized to open and the additional self-locking solenoid valve can be opened to ensure the smoothness of the main cylinder and the double input pipeline of ABS or ESP, so as to overcome the risk of adopting the shuttle valve. (3) Replace the normally open pressure reducing valve with the normally closed pressure reducing valve, so that when the active braking system needs to maintain pressure for a long time (the normally closed pressure increasing valve is closed), the pressure can be maintained for any long time by powering off the normally closed pressure reducing valve, which overcomes the problem that the normally open pressure reducing valve in the typical scheme shown in Figure 1 needs to be powered on to maintain pressure for a short time. However, two new problems are caused by the use of the normally closed pressure reducing valve in this scheme: the brake fluid pressure of the master cylinder cannot be released completely after the brake is completed. In the manual braking mode, the two input pipelines between the master cylinder and ABS or ESP cannot be powered on for a long time to keep on, so the manual braking cannot be realized. By paralleling two normally closed pressure reducing valves with a solenoid valve with self-locking function (referred to as self-locking solenoid valve), the self-locking solenoid valve can be kept open in case of power failure, and the double input pipeline between the main cylinder and ABS or ESP is opened, so as to ensure the effectiveness of the complete release of the hydraulic pressure of the main cylinder and the artificial braking, and solve the above two problems.

4. Accumulator Pressure Building Control Algorithm

In this system, accumulator is used to build pressure in advance, which shortens the time of building pressure. When braking is needed, the stored energy is released rapidly, and the braking force is generated instantly. At present, in most active braking systems, the pressure build-up control of accumulator adopts pure hydraulic pressure closed-loop. Although the method can accurately control the target pressure value, but the control process is complex, coupled with the lag and instability of the hydraulic pressure balance, resulting in a long period of pressure regulation, prone to oscillations, poor real-time performance, especially in the application scenario where continuous braking is required, it cannot supply the stored hydraulic energy in a timely and fast manner, resulting in a long response time of the braking system. In view of the shortcomings of the current control algorithm and the fact that the high-pressure accumulator is not the target pressure, and the control is in a certain range, which does not need special precise characteristics, a pressure building control algorithm of the accumulator is proposed, which combines the target pressure prediction and pressure feedback. The prediction methods of target hydraulic pressure include the estimation of continuous working time and the estimation of the number of rotations of hydraulic pump motor. According to the estimated parameters, the motor is controlled to make the hydraulic

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pressure in the high-pressure accumulator reach the preset target working pressure. During the control process, the hydraulic pressure sensor feeds back and monitors the pressure build-up situation in real time. When approaching the target pressure area, the pressure build-up is stopped. Assuming that V is the working volume of the accumulator, which can meet the demand of the brake fluid volume for one brake; q is the working flow of the hydraulic pump in unit time, the calculation formula of the continuous working time t of the hydraulic pump motor is:

$$\mathrm{t} = V/Q$$

The calculation formula of V and Q is

$$V = \frac{V_0(1-(P_2/P_3)^{1/n}}{(P_2/P_1)^{1/n}}$$

$Q = P_M + \vartheta_m + \vartheta_n/P_0$

In the formula, V0 is the nominal volume of the accumulator; P1 is the inflation pressure; P2 is the minimum working pressure of the accumulator; P3 is the maximum working pressure of the accumulator; n is the constant temperature index; Pm is the rated power of the pump motor; ηm is the efficiency of the pump motor; ηh is the efficiency of the hydraulic pump; P0 is the target pipeline pressure. If D is the displacement of the hydraulic pump and RM is the average speed of the pump motor, then t can also be calculated by the following formula

$$t = \frac{V}{r_m \times D}$$

5. Conclusion

This research combines active braking system and control algorithm, which not only ensures driving safety, improves road driving efficiency, but also reduces the difficulty of braking system control. In the process of vehicle braking and deceleration, it shows good smoothness and comfort, and has good practicability.

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