Research of Brake by Wire System and Inlet Check Valve

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ABSTRACT: Brake by wire (BBW) is a key technology for automotive braking systems to adapt to the intelligence and electrification of automobiles. This article introduces the EHB (Electro hydraulic Brake System) solution, which is one of the mainstream brake by wire solutions in the market. It also introduces the design requirements for the inlet check valve of the One Box solution in the EHB.

Keywords: brake by wire, one box, check valve

1. INTRODUCTION

The automotive industry is ushering in an era of change, and the automobile industry is rapidly developing towards the "new four modernizations" of electrification, intelligence, networking, and sharing. The new energy and intelligence of automobiles have not only brought fundamental changes to the power of automobiles, but also become a development trend in the field of drive-by-wire chassis. [1] According to the different implementation forms of passenger car wire brake systems, currently wire brake systems can be divided into two categories: electronic hydraulic brake (EHB) systems and electronic mechanical brake (EMB) systems. [2] At present, EHB is more widely used, similar to upgraded versions of traditional hydraulic systems. [5]

2. ELECTRONIC HYDRAULIC BRAKE SYSTEM

EHB uses electronic components to replace some mechanical components in traditional braking systems, retaining the mature and reliable hydraulic components. It has prominent advantages such as compact structure, fast response speed, easy to achieve regenerative braking, and precise control of braking force. [3] At the same time, EHB uses electric motor drive to establish brake pressure, no longer relying on the engine's vacuum source and vacuum booster to achieve brake assistance, solving the problem of vacuum source loss caused by the lack of engine in new energy vehicles. EHB has added a pedal feel simulator, which can achieve partial or complete decoupling of the pedals, achieve brake energy recovery, and well adapt to the development needs of new energy vehicles.[10]

The development of EHB has roughly gone through three stages, which can be divided into: ① high-pressure accumulators+motor pumps to achieve hydraulic assistance solutions, such as the

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Electrically Controlled Brake (ECB) developed by Toyota subsidiary ADVICS in Japan; ② Two BOX solutions, such as the iBooster+ESP product developed by Bosch; ③ ONE BOX solutions, such as the MKC1 product developed by Continental and the IPB product developed by Bosch.

Figure 1 ECB[4]

Figure 2 ibooster and ESP[4]

Figure 3 MCK1[4]

Figure 4 IPB[4]

One Box products, due to their high integration, compact structure, small footprint, light weight, and the advantages of fast response and precise pressure regulation, will increase the automobile assembly rate year by year.[5]According to research statistics from Zosi Automobile, the assembly rate of China's passenger car line control system was 20.5% and 76.6% in the One Box and Two Box markets in 2021, respectively. In the first five months of 2022, the market share of One Box and Two Box was 34.6% and 62.8%, respectively.

3. ONE BOX SYSTEM

The structural scheme of OneBox system is shown in Figure 5, mainly including brake pedal unit (BPU), hydraulic drive unit (HDU), mode switching unit (MSU), hydraulic control unit (HCU), and electronic control unit (ECU).

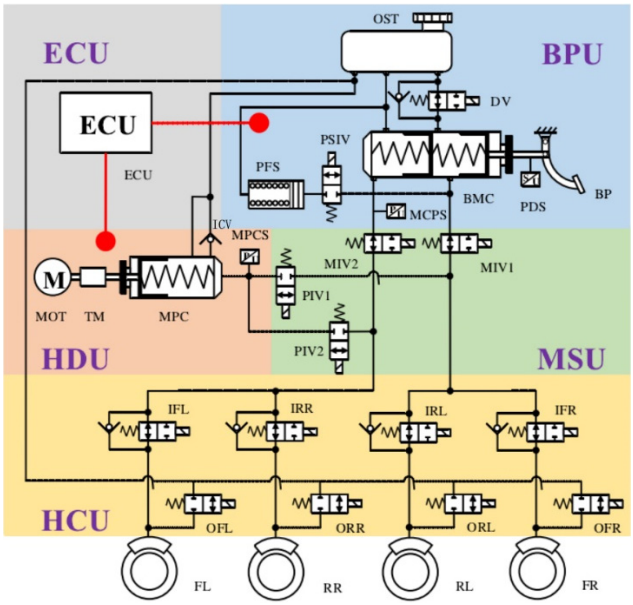

Figure 5 The structural scheme of OneBox system[4]

Table 1 Symbols and meanings of main components in the One Box system[4]

symbol	Meaning	symbol	meaning	symbol	meaning
OST	oil Storage tank	MOT	Motor	IFR	inlet valve of front right wheel
BP	brake pedal	TM	Transmission mechanism	OFL	outlet valve of front left wheel
PDS	Pedal displacement sensor	MPC	Motor pressure cylinder	ORR	outlet valve of rear right wheel
BMC	Brake master cylinder	ICV	Inlet check valve	ORL	outlet valve of rear left wheel
PFS	Pedal feel simulator	MPCS	Motor pressure cylinder pressure sensor	OFR	outlet valve of front right wheel
MCPS	Master cylinder pressure sensor	PIV1	First isolation valve of pressure building cylinder	FL	front left wheel
DV	Diagnostic valve	PIV2	second isolation valve of pressure building cylinder	RR	rear right wheel
PSIV	Pedal simulator isolation valve	IFL	inlet valve of front left wheel	RL	rear left wheel
MIV1	first isolation valve of Main cylinder	IRR	inlet valve of rear right wheel	FR	front right wheel
MIV2	second isolation valve of Master cylinder	IRL	inlet valve of rear left wheel	ECU	Electronic control unit

When the vehicle needs to brake, the driver presses the brake pedal, the PSIV is connected, and the brake fluid from the brake master cylinder enters the pedal simulator, which provides feedback to the driver on the pedal. At the same time, MIV1 and MIV2 are cut off, PIV1 and PIV2 are connected, achieving decoupling between the brake master cylinder and the wheel cylinder. The pedal position sensor collects the driver's braking intention signal and transmits it to the ECU. After analyzing and processing the signal, the ECU controls the motor to rotate at the specified angle at the specified speed. The rotation of the motor is transmitted to the motor pressure cylinder through the transmission mechanism to achieve pressure building. High pressure brake fluid enters the four wheel cylinders through the inlet valve, thereby pushing the wheel cylinder to hold the brake disc tightly and achieving brake braking.

4. ONE BOX system inlet check valve

To prevent high-pressure brake fluid from flowing back into the oil storage tank during the pressure building process of the One Box system motor pressure building cylinder, a one-way valve for fluid replenishment is installed at the outlet of the motor pressure building cylinder, which is the ICV shown in Figure 5. [8]If the single stroke of the motor pressure cylinder is not enough to establish sufficient braking pressure, the motor quickly reverses, driving the transmission mechanism to retreat. The transmission mechanism drives the piston in the motor pressure cylinder to retreat, and the pressure in the motor pressure cylinder rapidly decreases. The one-way valve for fluid replenishment opens, and the brake fluid in the oil storage tank flows into the motor pressure cylinder. After the brake fluid is replenished, the motor returns to normal transmission, and the transmission mechanism pushes the motor pressure cylinder to achieve pressure buildup again.

The force on the steel ball of the liquid replenishment one-way valve is shown in Figure 6.

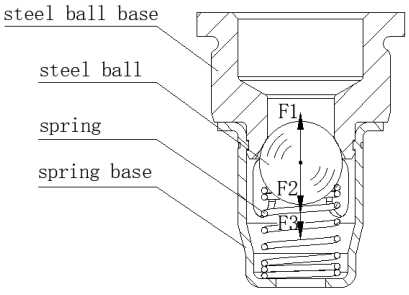

Figure 6 inlet check valve structure

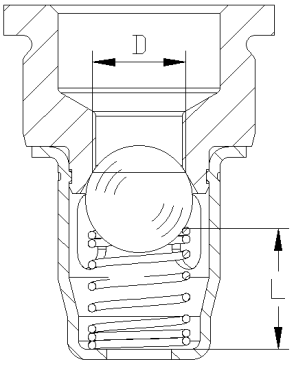

Figure 7 inlet check valve size

F1 is the force of spring acting on steel ball, and the spring bears compression force,[6] F2 represents the gravity of the steel ball, and F3 represents the hydraulic pressure exerted by the brake fluid in the oil storage tank on the steel ball. From the working process of the hydraulic one-way valve, it can be seen that in order to prevent brake fluid from flowing into the oil storage tank during pressure buildup in the motor cavity, the steel ball and the steel ball seat should fit together in the initial state,then

$$F1 > F2+F3 \quad (1)$$

When the piston in the motor pressure chamber retracts, the volume of the motor pressure chamber increases and the pressure decreases. The brake fluid in the oil storage tank, under the action of atmospheric pressure F4, pushes open the steel ball and enters the motor pressure chamber through the replenishment one-way valve, then

$$F1<F2+F3+F4 \quad (2)$$

Assuming the free length of the spring is L0, the spring stiffness is K, and the assembled length of the spring is L, as shown in Figure 7, then

$$F1= (L0-L)\ K \quad (3)$$

Let the weight of the steel ball be radius r, and the density of the steel ball be ρ, If the acceleration of gravity is g, then

$$F2=g\rho 4\pi r^3/3 \quad (4)$$

Assuming the diameter of the contact surface between the steel ball and the steel ball seat is D, as shown in Figure 7, the brake fluid density is ρ_1. If the difference between the height of the brake fluid level and the contact surface of the steel ball is h, then

$$F3=\rho_1 gh\pi D^2/4 \quad (5)$$

If the atmospheric pressure is set to P, then

$$F4=P\pi D^2/4 \quad (6)$$

From equations 1, 2, 3, 4, and 5, it can be concluded that

$$g\rho 4\pi r^3/3+\rho_1 gh\pi D^2/4< (L0-L)\ K< g\rho 4\pi r^3/3+ \rho_1 gh\pi D^2/4+ P\pi D^2/4 \quad (7)$$

From equations 1 and 2, it can be seen that if the replenishment one-way valve is to meet the usage requirements and the spring selection range of the replenishment one-way valve is wider, F2+F3 should be smaller than F4 as much as possible, and the smaller the value, the wider the spring force F1 selection range. According to equation 7, the weight of the steel ball for the replenishment one-way valve should be as small as possible, which can be achieved by reducing the diameter of the steel ball and selecting lightweight materials. At the same time, while reducing the diameter of the steel ball, it should also ensure the sufficient liquid passing capacity of the replenishment check valve. The distance between the replenishment one-way valve and the storage tank should be as close as possible, that is, when designing the One Box structure, the replenishment one-way valve should be set in a position close to the storage tank. The spring force is relatively small and has anti-corrosion requirements, and the material can be non-ferrous metal.[9]

5. CONCLUSION

With the rapid development of new energy vehicles in China, the wire controlled braking system has gradually become the preferred braking system for new energy vehicles, especially the One Box solution. Due to its outstanding product advantages, market share is rapidly increasing, and may become the main flow control technology solution for new energy vehicles.[7]

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