Upgrade of relay valve of SD type braking system for urban rail vehicles

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Abstract: Based on the structure and principle of the seven-stages relay valve of the SD type brake system of the existing urban rail vehicle, it is simply modified to double increase the number of stages of the braking force by each additional solenoid valve and piston-diaphragm. Therefore, the adjustment of the braking force is finer and more suitable for the precise positioning and parking of urban rail transit vehicles.

1. Introduction
The existing urban rail vehicle SD type brake system relay valve is a seven-stages relay valve, and the seven-stages relay valve is an electropneumatic valve which is electrically controlled and can perform addition and subtraction calculation. The command signal of the automatic controller comes through the excitation and degaussing of the three solenoid valves, so that the pressure air enters the diaphragm chamber of the seven-stages relay valve, add and subtract in different combinations, seven incremental values of air pressure can be obtained by the seven-stages relay valve, The pressure air of these different pressures is supplied to the brake cylinder to generate braking and release.

2. Construction of seven-stages relay valve
The upper part of the seven-stages relay valve is three commonly used solenoid valves (CZF1, CZF2, CZF3) and a pressure supply-discharge part, the middle part is a mixer, and the bottom part is the piston-diaphragm group (see Fig 1).

Commonly used solenoid valves are three Q23 x D type solenoid valves, and the working voltage is 110v DC. It consists of valve body, coil, iron core and spring. In addition, it has three air passages, and the pressure air output by the empty-heavy vehicle adjustment valve enters the lower valve port of the solenoid valve from the passage (28), the upper valve port opens to the atmosphere, and the side passage leads to the diaphragm chamber of the piston-diaphragm group.

The pressure supply-discharge part is a mechanism connecting the main air cylinder with the brake cylinder or the brake cylinder with the atmosphere. It consists of the spring of the supply-discharge valve, the supply-discharge valve, the large valve port, the acting rod, the throttle orifice, the pressure equalizing piston and the pressure equalizing diaphragm. When the pressurized air inflate the diaphragm chamber, the action rod moves upwards, first closing the exhaust port on the action rod, then opening the supply-discharge valve, and then opening the large valve port, so that the pressurized air from the passage (43) enters through the passage (20) to the brake cylinder. When the pressure air in the diaphragm chamber is discharged, the action rod moves downward, and the supply-discharge valve falls on the large valve port, and the exhaust port on the action rod leaves the supply-discharge valve, so that the pressure air in the brake cylinder is discharged into the atmosphere through the
exhaust port. When the pressure air in the M chamber above the pressure equalizing diaphragm is balanced with the pressure air acting on the piston-diaphragm group, the action rod is in the middle position, the supply-discharge valve is pressed on the large valve port, and the exhaust port on the action rod is still in contact with the supply-discharge valve, brake cylinder pressure air in pressure holding state. Two O-rings are installed on the plunger of the supply-discharge valve, the upper part of the plunger is connected with the brake cylinder, the purpose is to reduce the back pressure of the supply-discharge valve. There are two O-rings on the acting rod. The hollow passage of the acting rod communicates with the atmosphere, the lower part of the pressure equalizing diaphragm communicates with the atmosphere too, the lower end of the acting rod contacts the piston rod of the mixer.

The mixer consists of a piston rod, a piston and a diaphragm of the mixer. The N chamber above the diaphragm is connected with the pilot valve, and the E chamber below the diaphragm is connected with the emergency solenoid valve.

The piston-diaphragm group consists of three piston-diaphragms, namely, the upper piston and the common upper diaphragm, the middle piston and the common middle diaphragm, the lower piston and the common lower diaphragm. The effective area ratio of each piston-diaphragm is:

\[ S_{\text{upper}} : S_{\text{middle}} : S_{\text{lower}} = 7:6:4 \]

![Figure 1. Seven-stages relay valve](image)

1—valve body; 2—coil; 3—iron core; 4—spring; 5—spring of supply-discharge valve; 6—supply-discharge valve; 7—large valve port; 8—acting rod; 9—throttle orifice; 10—pressure equalizing piston; 11—pressure equalizing diaphragm; 12—piston rod; 13—piston; 14—mixer diaphragm; 15—upper piston; 16—common upper diaphragm; 17—middle piston; 18—common middle diaphragm; 19—lower piston; 20—common lower diaphragm; (8), (13), (20), (28), (43)—pathway

The piston-diaphragm group consists of three air chambers, namely, C1, C2 and C3, which are connected with CZF1, CZF2 and CZF3 commonly used solenoid valves, respectively.

There are six paths on the seat of the seven-stages relay valve (see Fig1). The path (28) is connected with the empty-heavy vehicle adjustment valve; the path (13) is connected with the pilot
valve; the path (43) is connected with the main air cylinder; the path (20) is connected with the brake cylinder; the path (8) is connected with the emergency solenoid valve; and another is connected with the atmosphere.

3. The function principle of the seven-stages relay valve
When braking in common use, the driver controls the controller to make three commonly used solenoid valves CZF1, CZF2 and CZF3 alternate excitation and demagnetization, three diaphragm chambers C1, C2 and C3 respectively inflate and exhaust. According to the different combination, the brake cylinder has seven pressure values. When the one-level braking command signal is issued, only the commonly used solenoid valve CZF1 is excited, then the output pressure air of the empty-heavy vehicle adjustment valve enters the diaphragm chamber C1 through the lower valve port of the solenoid valve CZF1. The air pressure acts on both the commonly used upper piston-diaphragm and the commonly used middle piston-diaphragm. The commonly used upper piston-diaphragm is subjected to upward force, while the commonly used middle piston-diaphragm is subjected to downward force. Because the area ratio of the two piston-diaphragms is \( \frac{S_{\text{upper}}}{S_{\text{middle}}} = \frac{7}{6} \), the action force of the commonly used upper piston-diaphragm is greater than that of the commonly used middle piston-diaphragm, so that the piston-diaphragms group is subjected to the upward action force, which is a step-by-step incremental value. It passes through the piston rod to the action rod, makes the action rod move upward, opens the supply-discharge valve, makes the air pressure in the main air cylinder enter the upper end of the supply-discharge valve and the brake cylinder through the big valve port, and enters the upper chamber M of the balancing piston through the throttle hole to achieve the balancing effect. When the pressure air entering the brake cylinder, i.e. the pressure air acting on the pressure equalizing piston-diaphragm balances the pressure air acting on the piston-diaphragm group, the acting rod moves downward and closes the large valve port under the action of the spring of the supply-discharge valve, thus keeping the pressure of the seven-stages relay valve in a holding state and keeping the pressure of the brake cylinder unchanged. When the brake cylinder pressure increases or decreases, the supply-discharge valve can automatically eliminate the increased pressure air or compensate the reduced pressure air to keep the brake cylinder pressure unchanged.

When release, the solenoid valve CZF1 de gaussing, indoor pressure air of the diaphragm chamber C1 through the lower valve port of the solenoid valve CZF1 exhaust to the atmosphere. Because the pressure equalizing piston-diaphragm is affected by the downward air pressure, the pressure equalizing piston and the acting rod are pushed downward, and the acting rod and the supply-discharge valve leave, opening the passage of the brake cylinder to atmosphere, the air of the brake cylinder is discharged to the atmosphere through the passage (20) and the hollow passage in the acting rod, at the same time, the air of the upper end of the supply-discharge valve and the balancing piston chamber M is discharged to the atmosphere through the throttle hole, so that the brake cylinder is in release.

Commonly used braking and release action 1~7 stages are exactly the same. Through the alternate excitation and de gaussing of commonly used solenoid valves, the brake cylinders get 1~7 stage-by-stage incremental values.

The common excitation and de gaussing of the 1~7-stage solenoid valve and the arrangement of the diaphragm chamber are shown in Table 1. In the maintenance process, in order to quickly find the commonly used braking fault, the maintenance personnel are required to memorize the following sequence of suction: first stage(1), second stage (2), third stage (1) (2), fourth stage (3), fifth stage (1) (3), sixth stage (2) (3), seventh stage (1) (2) (3).
Table 1: The excitation and degaussing of the 1~7-stage solenoid valve and the combination of the inflated diaphragm chamber when braking in common use.

| Driver controller handle position | Solenoid valve degaussing, excitation | Inflated diaphragm chamber | Output pressure stage |
|----------------------------------|----------------------------------------|----------------------------|-----------------------|
|                                  | CZF1 | CZF2 | CZF3 | no | no | no |
| Operating position               |      |      |      | no | no | no |
| 1                                | O    | —    | —    | C1 | 7-6 | 1  |
| 2                                | —    | O    | —    | C2 | 6-4 | 2  |
| 3                                | O    | O    | —    | C1+C2 | (7-6) + (6-4) | 3  |
| 4                                | —    | —    | O    | C3 | 4   | 4  |
| 5                                | O    | —    | O    | C1+C3 | (7-6) +4 | 5  |
| 6                                | —    | O    | O    | C2+C3 | (6-4) +4 | 6  |
| 7                                | O    | O    | O    | C1+C2+C3 | (7-6) + (6-4) +4 | 7  |
| Emergency braking zone           |      |      |      | E  | 8   | 8  |

Note: "O" means electric excitation, and "—" means no electric degaussing.

4. Upgrade and mathematical reasoning of the seven-stages relay valve

With the popularization of metro platform screen door, the precision of parking position of metro trains is becoming more and more high, which requires that the braking force of metro trains should be more precise and precise when parking. The existing SD type brake can only obtain a constant braking force of 7 stages. In order to meet the needs of precise positioning and parking of Metro trains, it is necessary to reform the existing SD type electro-pneumatic brake in order to obtain more stages of braking force.

By analyzing the structural principle of the seven-stages relay valve, in order to obtain more stages of braking force, it is necessary to increase the number of piston-diaphragms and corresponding solenoid valves in the common brake piston-diaphragms group. In order to save costs and improve efficiency, we strive to maximize the number of braking force stages that can be obtained for each additional piston-diaphragm. According to the area ratio of the three piston-diaphragms of the seven-stages relay valve, it is found that the area of the piston-diaphragm decreases from top to bottom, and the area of the upper piston-diaphragm is equal to $2^3-1$, which is also the maximum number of braking forces stages the relay valves of three piston-diaphragms group can adjust. The area difference between the upper and lower piston-diaphragm of the C1 chamber is $7-6=2^0$, and the area difference between the upper and lower piston-diaphragm of the C2 chamber is $6-4=2^1$. The area of the piston-diaphragm above the C3 chamber is $4=2^2$ (there is no piston-diaphragm below the C3 chamber).

Now verify the above rules. According to the above rules, if one piston-diaphragm and one solenoid valve are added, the braking force of $2^4-1=15$ stages can be modulated step by step at most. From top to bottom, the area of the piston-diaphragm is $2^4-1$, $(2^4-1) -2^0$, $(2^4-1) -2^0-2^1$, $(2^4-1) -2^0-2^1-2^2$, that is, the area ratio of the four piston-diaphragms from top to bottom is $15:14:12:8$. The top-down four inflatable diaphragm chambers are C1, C2, C3 and C4 in turn. Now verify whether the four piston-diaphragms group can adjust the incremental braking force of 15 stages step by step according to this area ratio. The list is as follows:
### Table 2: Common brake 1~15 stage inflatable diaphragm chambers arrangement table.

| Stage | Inflated diaphragm chambers | Output pressure stage |
|-------|-----------------------------|-----------------------|
| 1     | C1                          | 15-14                 |
| 2     | C2                          | 14-12                 |
| 3     | C1+C2                       | (15-14) + (14-12)     |
| 4     | C3                          | 12-8                  |
| 5     | C1+C3                       | (15-14) + (12-8)      |
| 6     | C2+C3                       | (14-12) + (12-8)      |
| 7     | C1+C2+C3                    | (15-14) + (14-12) + (12-8) |
| 8     | C4                          | 8                     |
| 9     | C1+C4                       | (15-14) +8            |
| 10    | C2+C4                       | (14-12) +8            |
| 11    | C1+C2+C4                    | (15-14) + (14-12) +8  |
| 12    | C3+C4                       | (12-8) +8             |
| 13    | C1+C3+C4                    | (15-14) + (12-8) +8   |
| 14    | C2+C3+C4                    | (14-12) + (12-8) +8   |
| 15    | C1+C2+C3+C4                 | (15-14) + (14-12) + (12-8) +8 |

Then verify the situation of the five piston-diaphragms. In the case of a combination of five piston-diaphragms, the area of the uppermost and largest piston-diaphragm should be $2^{5-1}=31$, which can modulate up to 31 stages of incremental braking force. The area ratio of the five piston-diaphragms from top to bottom is: $2^5-1:(2^5-1)-2^4:(2^5-1)-2^3-2^2:(2^5-1)-2^3-2^2-2^1$ in turn, i.e. 31:30:28:24:16. Now verify that the five piston-diaphragms combination can adjust the braking force of 31 stages in increments according to this area ratio. The list is as follows:

### Table 3: Common brake 1~31 stages inflatable diaphragm chambers arrangement table.

| Stage | Inflated template chambers | Output pressure stage |
|-------|-----------------------------|-----------------------|
| 1     | C1                          | 31-30                 |
| 2     | C2                          | 30-28                 |
| 3     | C1+C2                       | (31-30) + (30-28)     |
| 4     | C3                          | 28-24                 |
| 5     | C1+C3                       | (31-30) + (28-24)     |
|   | Combination                      | Values                          |
|---|----------------------------------|---------------------------------|
| 6 | C2+C3                            | (30-28) + (28-24)               |
| 7 | C1+C2+C3                         | (31-30) + (30-28) + (28-24)     |
| 8 | C4                               | 24-16                           |
| 9 | C1+C4                            | (31-30) + (24-16)               |
| 10| C2+C4                            | (30-28) + (24-16)               |
| 11| C1+C2+C4                         | (31-30) + (30-28) + (24-16)     |
| 12| C3+C4                            | (28-24) + (24-16)               |
| 13| C1+C3+C4                         | (31-30) + (28-24) + (24-16)     |
| 14| C2+C3+C4                         | (30-28) + (28-24) + (24-16)     |
| 15| C1+C2+C3+C4                      | (31-30) + (30-28) + (28-24) + (24-16) |
| 16| C5                               | 16                              |
| 17| C1+C5                            | (31-30) +16                      |
| 18| C2+C5                            | (30-28) +16                     |
| 19| C1+C2+C5                         | (31-30) + (30-28) +16           |
| 20| C3+C5                            | (28-24) +16                     |
| 21| C1+C3+C5                         | (31-30) + (28-24) +16           |
| 22| C2+C3+C5                         | (30-28) + (28-24) +16           |
| 23| C1+C2+C3+C5                      | (31-30) + (30-28) + (28-24) +16 |
| 24| C4+C5                            | (24-16) +16                     |
| 25| C1+C4+C5                         | (31-30) + (24-16) +16           |
| 26| C2+C4+C5                         | (30-28) + (24-16) +16           |
| 27| C1+C2+C4+C5                      | (31-30) + (30-28) + (24-16) +16 |
| 28| C3+C4+C5                         | (28-24) + (24-16) +16           |
| 29| C1+C3+C4+C5                      | (31-30) + (28-24) + (24-16) +16 |
| 30| C2+C3+C4+C5                      | (30-28) + (28-24) + (24-16) +16 |
| 31| C1+C2+C3+C4+C5                   | (31-30) + (30-28) + (28-24) + (24-16) +16 |

Due to the limitation of the length of the article, the reader can verify the combination of more piston-diaphragms according to the above rules.
5. The significance of the upgrade of the seven-stages relay valve

5.1. Braking force stages of the relay valve can be doubly increased

From the above analysis, it can be seen that the braking force stages of the relay valve can be doubly increased by adding a piston-diaphragm and corresponding solenoid valve. The more stages, the finer the adjustment of braking force during braking, and the more suitable it is for precise positioning and parking of metro.

5.2. Accuracy of braking force can be doubly improved

Accuracy of braking force provided by conventional analog braking control system is about ±20 kPa, and that of EP2002 braking control system can reach ±15 kPa. Taking the maximum brake cylinder pressure 450kPa of Beijing Metro Line 5 as an example, the brake cylinder pressure difference between two adjacent brake forces is about 450/63=7kPa when six piston-diaphragms and six solenoid valves are set in the common brake piston-diaphragm group of relay valves. It can be seen that the precision of braking force modulated by relay valve in SD type digital braking system is no less than that in analog braking system when there are enough common braking piston-diaphragms and solenoid valves.

6. Conclusion

6.1. Braking force stages of the relay valve

After modification of the seven-stages relay valve, each time a piston-diaphragm and a corresponding solenoid valve are added, through properly configuring the ratio of the area of several piston-diaphragms of the common brake piston-diaphragm group, the number of braking force stages can be doubled. Taking the relay valve of the common brake piston-diaphragm group containing n piston-templates as an example, the braking force of 2^n-1 step-by-step increment can be modulated at most, and the ratio of piston-diaphragm area from top to bottom in the common brake piston-diaphragm group is : \(2^n-1:(2^n-1)-2^0:(2^n-1)-2^0-2^1:......:(2^n-1)-2^0-2^1-...2^n-2\), where n is the number of piston-diaphragms or the number of solenoid valves in a common brake.

6.2. Adjustment precision of the braking force of the SD type digital brake system

After the above transformation, the adjustment precision of the braking force of the SD type digital brake system can compete with the stepless adjustment of the analog brake system, and can adapt to the demand for precise positioning and parking under the screen door device of the subway station.

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