Experimental study on dynamic and static characteristics of Differential Relay Valve

Zhe Wang\(^*\), Guangmin Li\(^1\), Min Liu\(^1\), Jun Liu\(^1\) and Yin Hong\(^1\)

\(^1\) Wuhan Second Ship Design and Research Institute, Wuhan, Hubei, 430200, China

\(^*\)Corresponding author’s e-mail: wangzhe@719.net

Abstract. This study aims to investigate the dynamic and static characteristics of a Differential Relay Valve (DRV). The fact that DRV has a complex physical structure leads to more nonlinear coupling property. Thus, theoretical analysis and simulation are not enough when studying its characteristics. In this article, the static and dynamic performance of a DRV is studied based on a novel test bench with NI Labview platform, and both the input and output gas pressure are detected in real time. The outcomes of the experiment show that both the service brake pressure and the parking brake pressure affect the output gas pressure of the DRV, and determined by the larger one. Moreover, the valve has good dynamical follow-up response performance.

1. Introduction

Pneumatic braking system has large braking force, low pollution and convenient maintenance compared with hydraulic braking system. A pneumatic braking system is mainly composed of air source, control valves and actuators[1]. Among them, the characteristics of control valves severely determine the braking performance. In the process of long-distance transmission, due to the compressibility of the gas, the hysteresis and fluctuation of the output pressure will affect the overall dynamic response performance of the system[2]. As the key control valve in the pneumatic braking system, the differential relay valve is installed at the end of the transmission system, which can effectively shorten the pressure build-up time and reduce the hysteresis effect, thereby improving the dynamic response performance. Liu[3] makes a detailed qualitative description of the structural principle and functional characteristics of DRV used in Hongyan vehicle. Zhu[4] briefly describes the application of DRV in a pneumatic brake system applied in all terrain crane named QAY180. However, none of them has established a test bench for testing and verifying.

2. Structure

Physical structure of a DRV is shown in Figure 1. The DRV is composed of 5 ports (1, 2, 3, 41, 42), 4 cavities (A, B1, B2, C), 2 pistons (\(a & b\)) and 1 spool (c). The four cavities consist of a gas supply cavity (A), two gas control cavities (B1&B2), and a gas outlet cavity (C). Among the five ports, port 1 is connected with gas source. Port 2 is gas outlet port. Port 3 is connected with atmosphere. Port 41 and port 42 are control ports, the former is related to service brake pressure and the latter is related to parking brake pressure, respectively. The output pressure of port 2 is determined by the control pressure from port 41 and port 42. The gas pressure in cavity B1 and B2 acts together on the two pistons \(a\) and \(b\). The exhaust port \(e\) between the piston \(b\) and the spool \(c\) controls the opening and closing of the cavity C, and the port \(d\) at the lower portion of the spool \(c\) controls the opening and closing of the cavity A and C.
Sketch of a pneumatic brake system for a multi-axle heavy vehicle is shown in Figure 2. The hand brake valve and treadle valve are usually located in the cab and the brake chamber with large volume are installed at the end of the long pipeline. If the output pressure of the two valves directly acts on the brake chamber, the brake response will exhibit hysteresis and the braking performance will be affected. To solve this problem, DRV is used and it is generally installed in the rear axle of chassis. Usually, the output pressure of the two brake valves in the cab are connected with port 41 and port 42 of a DRV, respectively. The gas source for the DRV (connected with port 1) are provided by the rear gas tank next to the brake chamber, so that the output pressure of the valve can directly act on the brake chamber (connected with port 2). Thereby, the charging and discharging time of the brake chamber are shortened, and the response speed of the brake system are improved.

3. Test Bench

The fact that DRV has a complex physical structure leads to more nonlinear coupling property. Thus, theoretical analysis and simulation are not enough when studying its characteristics. Thus, a test bench for DRV is built in this article, as shown in Figure 3.

The test bench is mainly composed of two parts: the worktable and the measurement system. Firstly, the worktable is mainly made of three gas circuits. Figure 4 shows the schematic diagram of the layout of the test bench (1-Load sensing proportional valve, 2&8-two-position two-port solenoid valve, 3&5-two-position three-port solenoid valve, 4-gas tank, 6&7-gas pressure sensor). The load sensing proportional valve in each circuit regulates pressure value. The solenoid valve controls the opening or closing of each circuit and the gas measurement sensor is used to detect the pressure value of the inlet port and outlet port.

Then, the measurement system consists of hardware and software. While, the hardware is made of Advantech 610H industrial computer, Panasonic PLC, high performance NI data acquisition card PCI-6229 and high-precision, fast response pressure sensor and other instruments. The pressure regulation of the proportional valve is controlled by the output voltage signal from the AO (Analog output) card. The solenoid valve is controlled by the DO (Digital output) card. The communication between PLC and host computer is realized by using TCP/IP interface through OPC protocol. The software is developed on the LabVIEW platform of NI Company. The interface of the software is friendly. It performs well in data acquisition, processing and storage, real-time display, control and execution. Figure 5 shows the man-machine interface of the test software for DRV.
Figure 3. Test bench for DRV.

Figure 4. Schematic diagram of the test bench.

Figure 5. Interface of the test software.

The constant pressure source was set as 800kpa. In the test of static characteristics, the parking brake pressure is set as 400 kPa, while the service brake pressure is set as follows, firstly, increasing from 0 kPa to 600 kPa within 20 s, and then maintaining 600 kPa for 10 s, and finally slowly dropping to 0 kPa within 20 s.

In the test of dynamic characteristics, the parking brake pressure is set to a constant pressure of 400kPa, and the service brake pressure is changed from 0kpa to 600kpa within 0.5s, and then rapidly drops to 0kpa within 0.5s after 20 seconds.

4. Results and Discussion
The test results of the DRV are shown in Figure 6 and Figure 7.

As can be seen from Figure 6, during t1, the service brake pressure is less than the parking brake pressure, and the outlet air pressure is equal to the parking brake pressure, independent of the service brake pressure. During t2, the service brake pressure begins to be higher than the parking brake pressure, first increases and then decreases. At this time, the outlet pressure changes with of the service brake pressure, which is approximately equal to the service brake pressure. During t3, the service brake pressure begins to be less than the parking brake pressure, and the exhaust pressure changes with the parking brake pressure, which is not affected by the service brake pressure. In addition, it can be seen from the dynamic characteristic curve in Figure 7 that the outlet gas pressure of the differential relay valve is equal to the larger value of the service brake pressure and the parking brake pressure.

In addition, Fig 7 indicates that in the dynamic characteristic test, when the service brake pressure stepped up from 0kpa to 600kpa, it only took 0.2s for the outlet gas pressure to rise from 400kpa to 600kpa. This shows that the DRV has a good dynamical follow-up response performance.

Moreover, label “a” in Fig 6 and Fig 7 show slight overshoot of the outlet gas pressure, which is caused by the impact of a step increase of the parking brake pressure, but it soon stabilizes. The gas source pressure at label “b” shows a step drop. This is caused by the rapid input of parking brake pressure, the exhaust valve is opened instantly, and the air flow area suddenly increases. Both c1 and c2 are the inflection points for the rise of outlet gas pressure. When comparing these two points, it shows that when the service brake pressure rises slowly, the output gas pressure changes smoothly, and when the service brake pressure rises rapidly, the output gas pressure and gas source pressure fluctuate.
5. Conclusion
A test bench for studying the static and dynamic performance of a DRV is built in this paper.
- The test results show that both the service brake pressure and the parking brake pressure affect the output gas pressure of the DRV, and the output pressure is determined by the larger one. Moreover, the valve has good dynamical follow-up response performance.
- An experimental test system was built, and the proposed test method and the obtained test data provided support for further research of the DRV.

References
[1] Wu, J.L., Zhang, H.C. (2009) Robust design of a pneumatic brake system in commercial vehicles. SAE Int. J. Commer. Veh., 2(1):17-28.
[2] Wang, Z., Zhou, X.J., Yang, C.L., Chen, Z.M. (2017) An experimental study on hysteresis characteristics of a pneumatic braking system for a multi-axle heavy vehicle in emergency braking situations. Appl. Sci., 7, 799.
[3] Liu, Y. (2003) Discussion on the application of differential relay valve in Hongyan car. Chongqing Heavy Truck Technology, 1:4-8.
[4] Zhu, C.J. (2015) Research on comprehensive braking strategy of heavy multi axle vehicle. Changan University.
[5] Xiang, Z., Tao, G.L., Xie, J.W. (2008) Simulation and experimental investigation on pressure dynamics of pneumatic high-speed on/off valves. Journal of Zhejiang University, 5:845-849.
[6] Selvaraj, M., Gaikwad, S., Suresh, A.K. (2014) Modeling and simulation of dynamic behavior of pneumatic brake system at vehicle level. SAE Technical Paper, 7.
[7] Jonathan I.M., David C. (2010) A high performance pneumatic braking system for heavy vehicles. Vehicle System Dynamics, 48:S1, 373-392.