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Bench Test on Static Characteristics of the Foot Braking Valve

[1]Zhang Peng, [1]Xu Bao, [2]Fu Dechun and [3]He Le
[1]School of Mechanical Electronic and Information Engineering,
China University of Mining and Technology, Beijing, Beijing 100083, China
[2]Jin Wan An Corporation, Beijing 100084, China
[3]State Key Laboratory of Automotive Safety and Energy, Tsinghua University,
Beijing 100084, China

Abstract: The foot braking valve is an important component of the EBS. The structure and working principle of a foot braking valve were introduced. The test bench of the foot braking valve of the EBS was built. The static characteristics of the foot braking valve were obtained via the bench test. It is showed that the valve ports of the two air channels are opened at the displacement of 3.6 mm. The inflection points and slope of each segment of the pressure curve obtained by the bench test are basically identical to those of the static characteristic calibration curve. The thrust force through the bench test does not reach the maximum force of calibration curve because the air source pressure does not reach the required test pressure.

Key words: Foot braking valve, static characteristics, bench test, EBS

INTRODUCTION

EBS (Electronically Controlled Braking System) is developed to apply for the air braking system of the commercial vehicles based on Anti-lock Braking System (ABS) and Acceleration Slip Regulation (ASR) (Luo and Zhang, 2009; Wu, 2004; Yang, 2004). It adopts the electronic control to replace the traditional mechanical transmission control and pure pneumatic control, reduces the mechanical hysteresis, shortens the braking distance, makes the brake more accurate and prolongs the lifespan of brake linings (Li, 2010; Luo and Zhang, 2009). The foot braking valve is an important components of the EBS. The foot braking valve (i.e., foot valve) is namely the braking signal transmitter which transmits the braking signals including the braking start signal and the braking intensity signal. When the circuit works properly, the foot valve transmits the braking start signal and braking intensity signal to the ECU, then ECU will complete the braking by controlling the rest of the brake system. When the circuit fails, the two pressure outputs of the foot valve as the backup pressure air will still be respectively transported to the front and rear axle module of the EBS. They will become the key factor of regulating the front and rear axle module's braking pressure. The static characteristics of the foot valve concern the braking performance and braking comfort. So the research on the foot valve of the EBS is particularly important.

The structure and working principle of a foot valve will be analyzed. The static characteristics of the foot valve will be obtained via the bench test.

FOOT VALVE'S STRUCTURE AND WORKING PRINCIPLE

The foot valve generally uses the dual air loop and single-circuit loop structure. The dual air loop is designed to guarantee that the other air channel still make the foot valve work properly when one air channel fails. Fig. 1 is the structure diagram of the foot valve.

As can be seen from Fig. 1a, 61, 62 are the two electrical interfaces. 11 and 12 are the two air inlet ports and 21 and 22 are the two air outlet ports. The first digit 1 represents the inlet, while 2 represents the outlet. The second digit 1 represents air channel 1, while 2 represents air channel 2. The two outlets are respectively connected to the front and rear axle module of the EBS.

As can be seen from Fig. 1b, 1, 2, 3, 4 are the four signal pins which definitions are as follows: (1) the high level, (2) the low level, (3) the output switching signal and (4) the output PWM (Pulse Width Modulation) signal. When the foot valve is working, 1 port is connected with the power supply, 2 port is connected with the ground lines, 3 port transmits the brake switching signal to the ECU, 4 port transmits the PWM signal which is converted by the displacement sensor of the foot valve to the ECU.

Corresponding Author: Zhang Peng, School of Mechanical Electronic and Information Engineering,
China University of Mining and Technology, Beijing, Beijing 100083, China

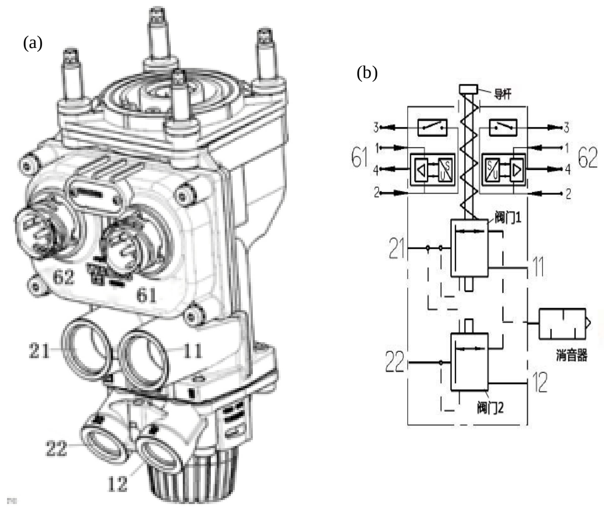

Fig. 1: Structure diagram of a foot valve

The structure and function of two circuits are identical. The two circuits together ensure the accuracy and anti-interference of the electrical signal transmission.

THE STATIC CHARACTERISTIC TEST BENCH OF THE FOOT VALVE

The setup of the test bench: The foot valve includes electrical and pneumatic parts. The test bench is designed to collect the foot valve's signal and measure its static characteristics. The test bed has the necessary air connections, a variety of sensors and data acquisition system. The software of our laboratory can run in the windows XP environment and display the acquisition data on a computer in the form of the curve. It makes the test data more intuitive and helps us to analyze the characteristics of the foot valve. The setup of the test bench is shown in Fig. 2.

The components and functions of the test bench are as follows. The foot valve and acquisition system are powered by 24V DC power supply. Data acquisition and analysis system is comprised of the computer and the 64-bit acquisition card which can obtain the sensor signal and the foot valve internal signal. The oscilloscope is used to read the duty cycle of the PWM signal. The BK-4B force sensor is used to measure the force of the guide rod. The displacement sensor is used to measure the displacement of the guide rod. The three pressure sensors are used to measure the pressures of the air source and the foot valve's two outlet. The air compressor is the air source. The 1L air tank is the storage of compressed air. The two decompressing valve are used to regulate the pressure of air channel. The cylinder is the executive element and pushes the guide rod down. The three positon five-way valve is used to control the movement of the cylinder.

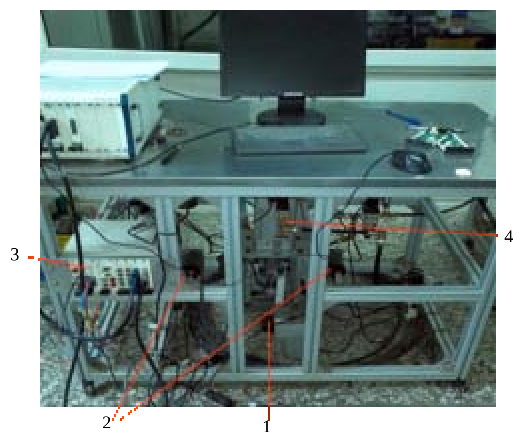

Fig. 2: The setup of the test bench, 1: Foot valve, 2: Pressure sensors, 3: Data acquisition system and 4: Cylinder

The working principle of the test bed: Figure 3 is the working principle diagram of the foot valve test bench which includes the components as follows. 1,1' is the air tank, 2,2' is the pressure reducing valve, 3 is the pressure sensor, 4 is the three position five-way valve, 5 is the cylinder, 6 is the force sensor, 7 is the cylinder rod, 8 is the foot valve, 9 is the displacement sensor and f1, f2 are respectively load 1 and load 2.

As can be seen from Fig. 3, that the air tank 1 pushes the foot valve through the cylinder is used to simulate the

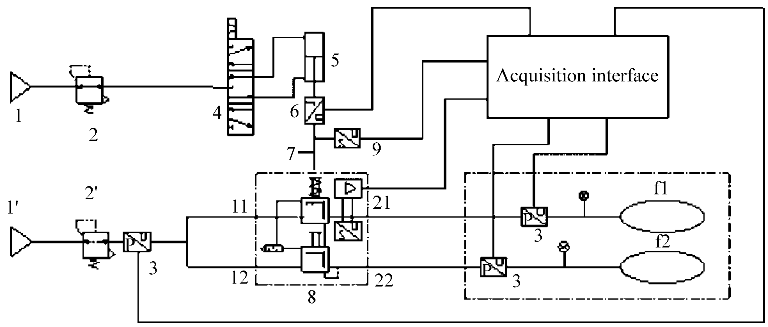

Fig. 3: The working principle diagram of the foot valve test bench

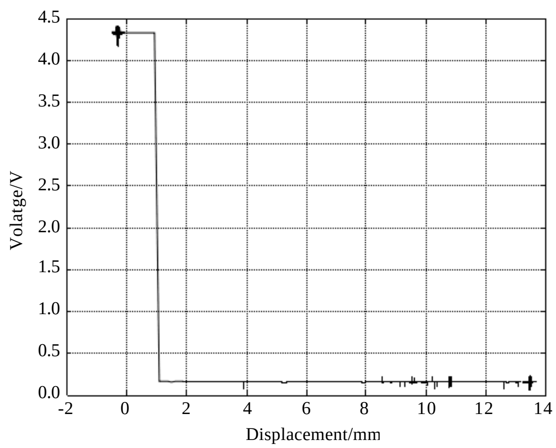

Fig. 4: Relation curve between the switch and the displacement

action of the foot pedal stepped by the foot. The air tank 1' is used to supply the air for the two inlets of the foot valve. The pressure sensor measures the air source pressure when the decompressing valve 2' is fully opened. When the three position five-way valve is in the upper position, the cylinder's rod will push the guide rod of the foot valve to make its piston move. The air supplied by the air tank 1' is outputted through the outlet. The different thrust can be obtained by adjusting the cylinder's pressure. This thrust makes the pistons of the foot valve's two air channels achieve the force equilibrium at the corresponding positon where the thrust, the pressures of outlet ports 11 and 22, PWM signal duty cycle, respectively can be acquired. When the three position five-way valve is in the lower position, the cylinder's lower chamber intakes and the upper chamber exhausts. The cylinder's rod will moves up and the guide rod of the foot valve will restore the initial position.

BENCH TEST DATA PROCESSING AND ANALYSIS

By using Matlab software to process the test data, the static characteristics of a foot valve are analyzed as follows.

The switching signal represents that the foot valve sends the braking start signal to the ECU of the braking system. Figure 4 shows the relationship between the braking switch signal and the displacement.

As can be seen from Fig. 4, the braking switch signal is a step signal. This signal is the high level before the braking starts. When the brake displacement reaches 1.1 mm, the switching signal turns the low level and the braking starts at this time. The foot valve transmits the braking start signal to the ECU, then the brake is completed by the ECU controlling the system. Since the switching signal remains the low level, it means that the brake has been continued.

The two output pressures of the foot valve are respectively expressed as p1 and p2. Figure 5 shows the relationship between the output pressures and the displacement.

As can be seen from Fig. 5, the two air channels' time to open is almost consistent. The specific pressure build rule is as follows. The valve port is not opened and the outlet pressure does not establish when the displacement is 3.6 mm or less. The valve port begins to be opened and the output pressure begins to be established when the displacement is 3.6 mm. When the displacement is 3.6 ~3.7 mm, the valve port is just opened and the pressure characteristics of rapid building is reflected. When the displacement is 3.7 ~10.0 mm, the valve port is gradually opened, the relationship between the pressure and displacement is linear and the slope of the line is 0.79. When the displacement is equal to 10.0 mm, the valve port is fully opened and the two outlet pressures increase rapidly to the same as the gas source. The displacement increases, while the outlet pressure remains constant if the thrust force continues to increase at this time.

The effective time of PWM signal reflects the braking extent of the foot valve. ECU can carry out the braking force distribution according to the size of this signal. Figure 6 shows the relationship between the effective time of the PWM signal and the displacement.

The duty cycle of PWM signal maintains 12.35% displayed by the oscilloscope when the displacement is

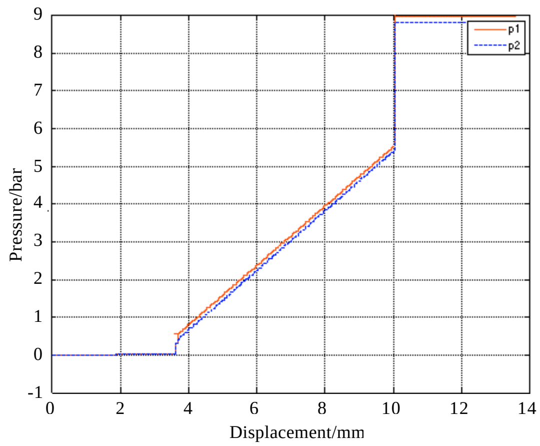

Fig. 5: Relation curve between the outlet pressure and the displacement

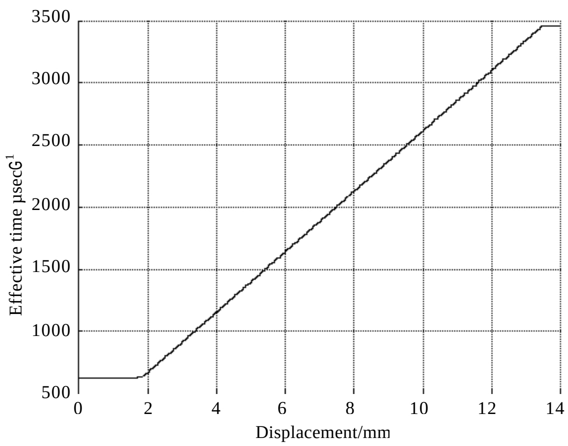

Fig. 6: Relation curve between the effective time of the PWM signal and the displacement

0~ 1.9 mm. Since the PWM signal's output cycle is 5.14 m sec, the effective time is expressed as:

$$5.14\times12.35\,\%\approx635\ \mu\ \text{sec}$$

The results are agree with the experimental results of Fig. 6. As can be seen from Fig. 6, the relationship between the pressure and displacement is linear at the displacement of 1.9~13.5 mm. It indicates that it will transmit the greater braking intensity signal and the brake pressure of the front and rear axle distributed by ECU will be greater when the foot valve is depressed more deeply. The effective time maintains 3458 μsec after the displacement of 13.5 mm.

The relationship between the thrust force and the displacement concerns the flexibility and comfort of the foot pedal stepped. It is a significant performance indicators. Figure 7 is the the relationship between the thrust force and the displacement.

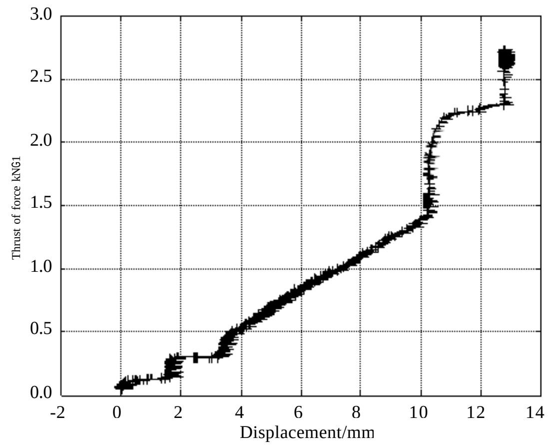

Fig. 7: Relation curve between the thrust force and the displacement

As can be seen from Fig. 7, the thrust force is approximately 128 N at the displacement of 0~1.6 mm, 300 N at the displacement of 1.6~3.2 mm, a linear segment whose slope is 151 N mm^{-1} at the displacement of 3.5 mm$\le$x$\le$10.2 mm. The above thrust forces are basically identical to the static characteristic calibration curve. While the thrust force is approximately 2250 N at the displacement of 10.2 mm$\le$ x$\le$12.8 mm, which is lower than 2750 N of the static characteristic calibration curve. The reason may be that the air source pressure does not reach the maximum pressure of the static characteristics calibration curve.

CONCLUSION

The basic structure and the working principle of the foot valve were introduced. The static characteristic test bench of the foot valve was designed and built. The static characteristic curves of the foot valve are obtained via the bench test. Two air channels' time to open is consistent. The inflection points and slope of each segment of the pressure curve obtained by the bench test are basically identical to the static characteristic calibration curve. The thrust force does not reach the maximum force of the static characteristics calibration curve because the air source pressure does not reach the required test pressure.

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