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Computer Simulation of the Foot Braking Valve Based on AMESim

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Abstract: The foot braking valve is an indispensable component in EBS. The pneumatic simulation model of the foot braking valve in EBS system was built up through AMESim. The simulation model was verified to be correct by the experiment. The pressure dynamic characteristics in several different input signals were analyzed. The pressure built-up process in the step thrust input has the overshoot of the pressure of circuit 1 is 0.0792 bar while circuit 2 is 0.0672 bar. The pressure of the foot valve's two circuits reaches 10bar at about 1.75s, the exhausting starts at 3.1s and the whole exhausting process takes about 0.85s in the ladder pressure increasing trust input. The simulation results indicate that the foot braking valve's pressure dynamic characteristics is good.

Key words: Computer simulation, foot valve, dynamic characteristics, AMESim

INTRODUCTION

With the sharp increase in the car ownership and the increased vehicle speed, the road traffic accidents have become a worldwide social problem. The automotive braking system guarantees the safe driving, so the electronic control technology to improve the performance of the braking system and extend its function has been received the extensive attention. 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 (Luo and Zhang, 2009). While the foot braking valve (i.e. foot valve) is an indispensable component in EBS, whose pressure dynamic characteristics counts for much when the circuit breaks down, in addition to transmitting the electric braking signal in EBS' normal working condition. The pressure dynamic characteristics concern the braking performance and braking comfort.

All in all, the foot valve makes so much on the security, reliability and practicality of the braking system. So the research aimed at the foot valve appears especially important.

The structure and working principle of a foot valve will be analyzed. The pneumatic system of the foot valve will be modeled, simulated and analyzed through AMESim (Fu and Qi, 2011; Zhao, 2010).

FOOT VALVE'S STRUCTURE AND WORKING PRINCIPLE

Fig.1 is the simple structure principle diagram of a type of foot valve. The foot valve has two main gas circuit, namely the circuit 1 which is from the inlet 1 to the outlet 1 and the circuit 2 similar to the former. Two circuits are respectively by two pistons to open or close the valve port to control the pneumatic on-off.

As can be seen from Fig. 1, the push rod goes down to compress the spring K1, overcome the gap between the push rod and the piston 1 when the foot pedal is stepped down. And the spring K2 is compressed, comes into contact with the spring seat 1. Then the vent A is closed while the valve port 1 is open. The gas enters into the braking chamber which is formed by the underside of piston 1 and the valve body through the valve port 1. As a result, the pressure of circuit 1 has been built up. The pressure relates to the force on the push rod which is the force exerted on the pedal by the foot. This pressure makes the piston 1 under the pressure, the thrust and the other forces to achieve equilibrium. After the pressure of the circuit 1 (p1) has been built up, the gas enters into the upper chamber of the piston 2 through vent B and then

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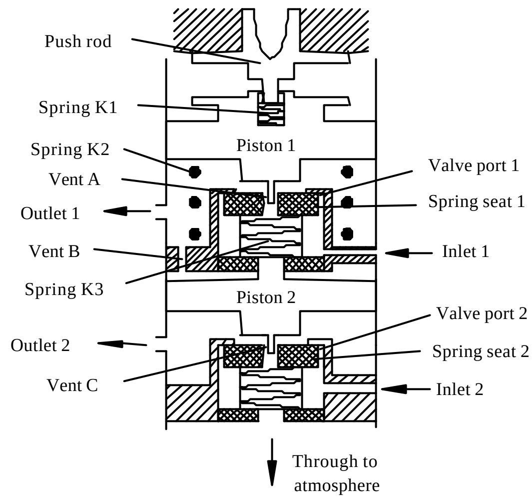

Fig. 1: Structure diagram of a foot valve

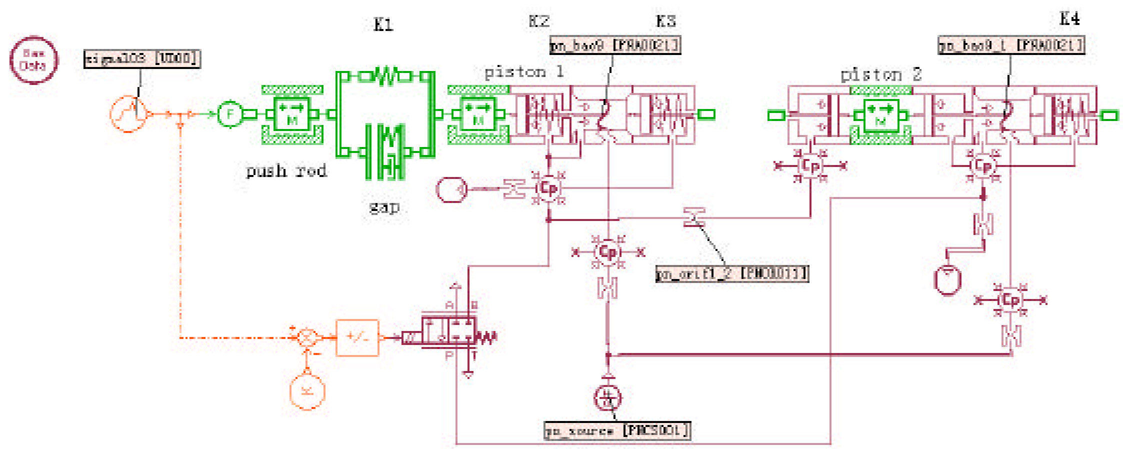

Fig. 2: Aerodynamic model of a foot valve

pushes the piston 2 to open the valve port 2. So the pressure of circuit 2 is built up. The piston 2 achieves the force balance similar to the piston 1. Significantly, in conventional braking system, the outlets are connected directly to the brake cylinder. While the two outlets are respectively connected to the front and rear axle module in EBS.

AERODYNAMIC MODEL OF THE FOOT VALVE

The aerodynamic model of a foot valve is shown in Fig. 2. A variable signal source input is used to simulate the thrust and to achieve the "pressure-increasing, pressure- holding, pressure-reducing" processes. The experimental results and theoretical analysis indicate that the piston can not push the spring seat to close the vent and open the valve port. So the exhausting process can be simulated by a constant signal source combined with a variable signal source. This model uses the user-defined valve PNAO021 to represent the two valves of the foot valve and two chambers with 1L volume to represent the brake cylinders.

The model parameters are setted according to the experiment and measurement results which are shown in Table 1.

EXPERIMENTS

Experiment setup is shown in Fig. 3. The foot valve and acquisition system are powered by 24 V DC power

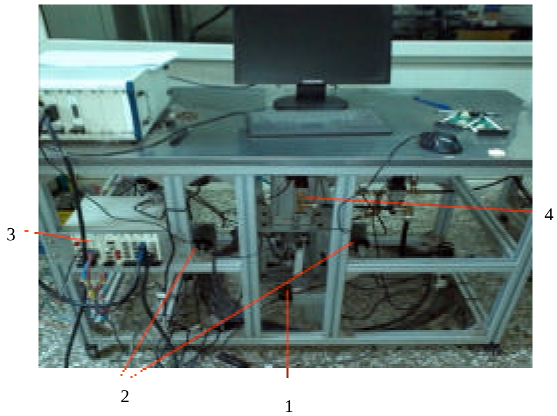

Fig. 3: Experiment setup, 1-Foot valve, 2-Pressure sensors, 3-Data acquisition system 4-Cylinder

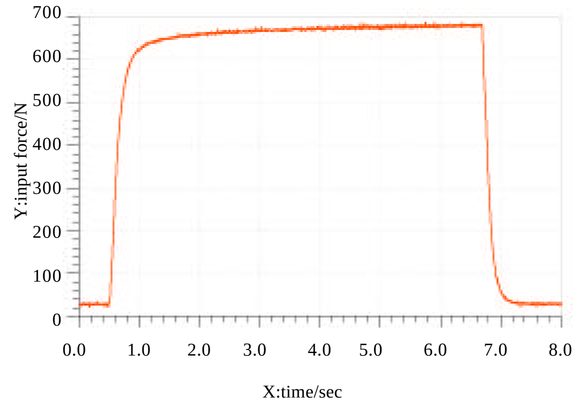

Fig. 4: Experimental input force

Table 1: Foot valve model parameters

Parameter names	Value
Mass of push rod/kg	0.08
Spring rate of K1/N/mm	3500
Gap/mm	1.6
Mass of piston 1/kg	0.35
Piston diameter/mm	50
Piston rod diameter/mm	16
Spring rate of K2/N/mm	6.76
Mass of piston 2/kg	0.01
Spring rate of K3/N/mm	1.09
Spring rate of K4/N/mm	1.09
Spring seat diameter/mm	26

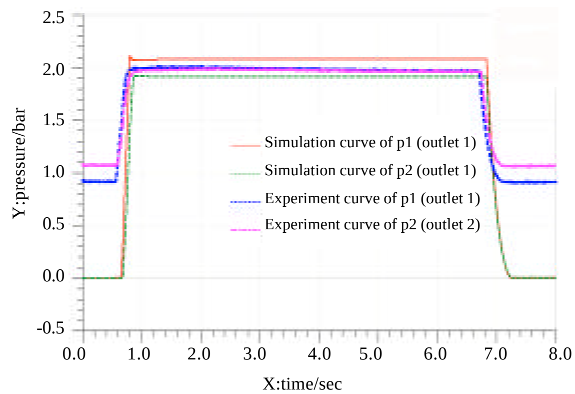

Fig. 5: Simulation results in comparison with the experimental results

supply. Data acquisition and analysis system is comprised of the computer and the acquisition card. And it can obtain the sensor signal and the foot valve internal signal. The pressure sensors are used to measure the pressure of the gas source and the foot valve outlet. The cylinder is the executive element and pushes the foot valve guide rod down.

Replace UDO0 with UDA01 and read a data file of one collection experiment whose input force is shown in Fig. 4. The dynamic characteristic comparison results between the experiment and the simulation are shown in Fig. 5.

As can be seen from Fig. 5, except the beginning and end of the curves does not appear exactly which is due to the measuring atmosphere pressure of two circuits in the beginning of the experiment, the simulation curve almost correctly reflect the relation between pressure and time.

SIMULATION RESULTS

All kinds of working conditions are simulated via inputting the corresponding various thrust on the push rod. After running the simulations, the two outlets' pressure characteristics, including the rapidity and stability of the pressure built-up are analyzed as follows.

Pressure dynamic characteristics of the "pressure increasing-pressure holding-pressure reducing" process

Figure 6a shows a input force curve used to simulate a "pressure increasing-pressure holding-pressure reducing" process. The simulation time is set to 2s and the communication interval is 0.001s. The simulation results of the push rod' displacement and the pressure dynamic characteristics are shown in Fig. 6(b-c).

As can be seen from Fig. 6b, the maximum stroke of the push rod is 12.4 mm. In the linear pressuring and linear decompression process, the push rod displacement smoothly rises and falls step to step. And the displacement curve is not symmetrical. This is because the push rod is not limited in its return stroke.

As can be seen from Fig. 6c, the valve port is opened at 0.14s under the given force. The pressures of circuit 1

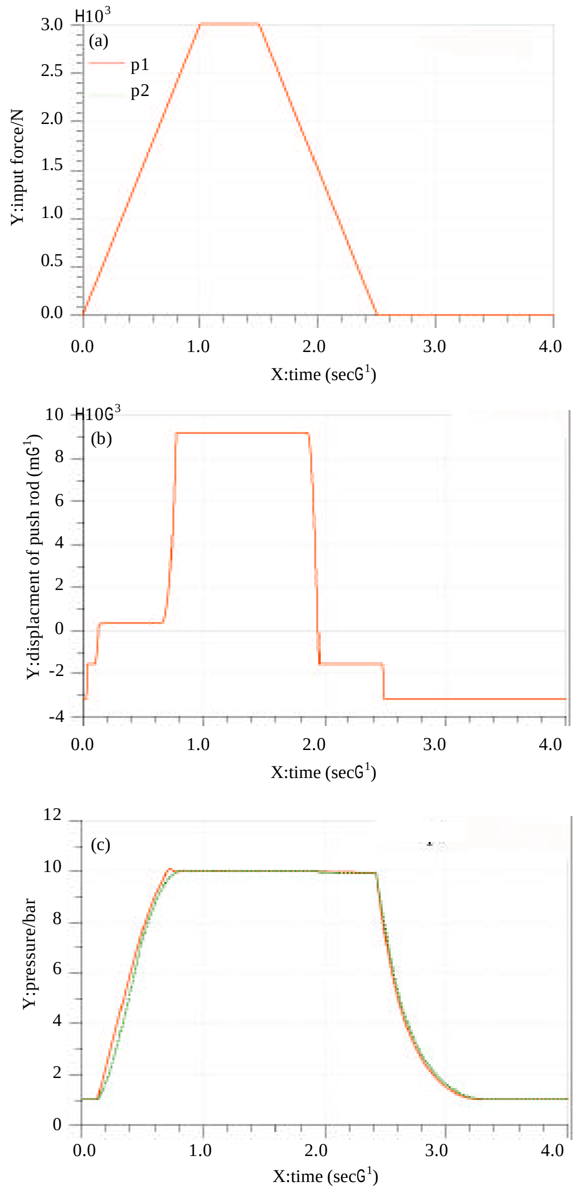

Fig.6(a-c): (a)In the "pressure increasing-pressure holding-pressure reducing"thrust input, simulation results of (b) the push rod's displacement and (c) the pressure dynamic characteristics

and circuit 2 are built up almost at the same time. And the pressure built-up process is stable. The pressure of circuit 1 is slightly higher than that of circuit 2 which accords with the results obtained by the force balance of piston2. At 0.8s, the valve port is completely open so that the circuit output pressure and the supply pressure are equal. At 2.42s, the pressures of the two circuits begin to drop. The pressure drops to the atmosphere pressure at about 3.27s. The exhausting process in situation that the thrust reduces linearly takes approximately 0.85s.

Pressure dynamic characteristics in the step input: Compared with other common input, the dynamic performance of the system in a step input tends to be worst. If the system in a step input can still maintain the good performance, it shows that the system can meet the performance requirements. The dynamic characteristics of the foot valve in a step input is simulated. Figure7a shows the step thrust input curve.The simulation time is set to 2s and the communication interval is 0.001s. The simulation results of the push rod's displacement and the pressure dynamic characteristics in the step thrust input are shown in Fig. 7(b-c).

As can be seen from Fig. 7b, the foot valve' push rod is instantly stepped in the end moment without any fluctuations when it is exerted on a step input force.

As can be seen from Fig.7c, the pressure built-up time is approximately 0.25 sec. This pressure built-up time is shorter than that of the linear pressurization process. In fact, the pressure built-up time in the condition of the linear pressurization process relies on the slope of this linear pressurization process. But the applied pressure is instantaneous in the step thrust input, so the two pressure built-up time is not comparable. As you can see, the pressure built-up process in the step thrust input has the overshoot: the overshoot of the pressure of circuit 1 is 0.0792bar while circuit 2 is 0.0672 bar. However, they are very small. Therefore it is shown that the dynamic performance of the two circuits' pressure output is good in the step input.

Pressure dynamic characteristics in the ladder pressure increasing input: In practical cases, the drivers tend to step on the pedal in a stepwise manner. In order to study the foot valve' pressure dynamic characteristics in this situation, the thrust input is set to the ladder pressure increasing which is shown in Fig. 8a.The simulation time is set to 4s and the communication interval is 0.001s. The simulation results of the push rod's displacement and the pressure dynamic characteristics in this thrust input are shown in Fig. 8(b-c).

As can be seen from Fig. 8c, at 0.1s, the pressure rises in step with the thrust regularly which increases like the stairs. It indicates that the performance of the foot valve's pressure dynamic characteristics is good. Curves here has one stair less than those of Fig. 8b. It is because the pressure reached to be the same with the gas source

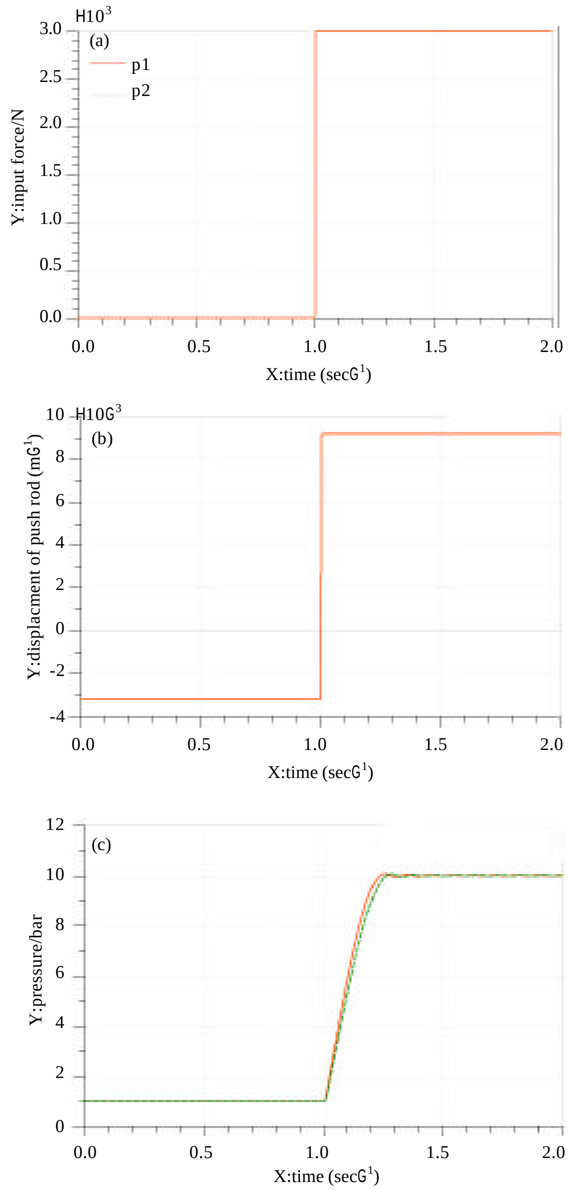

Fig.7(a-c): (a) In the step thrust input, simulation results of (b) the push rod's displacement and (c) the pressure dynamic characteristics

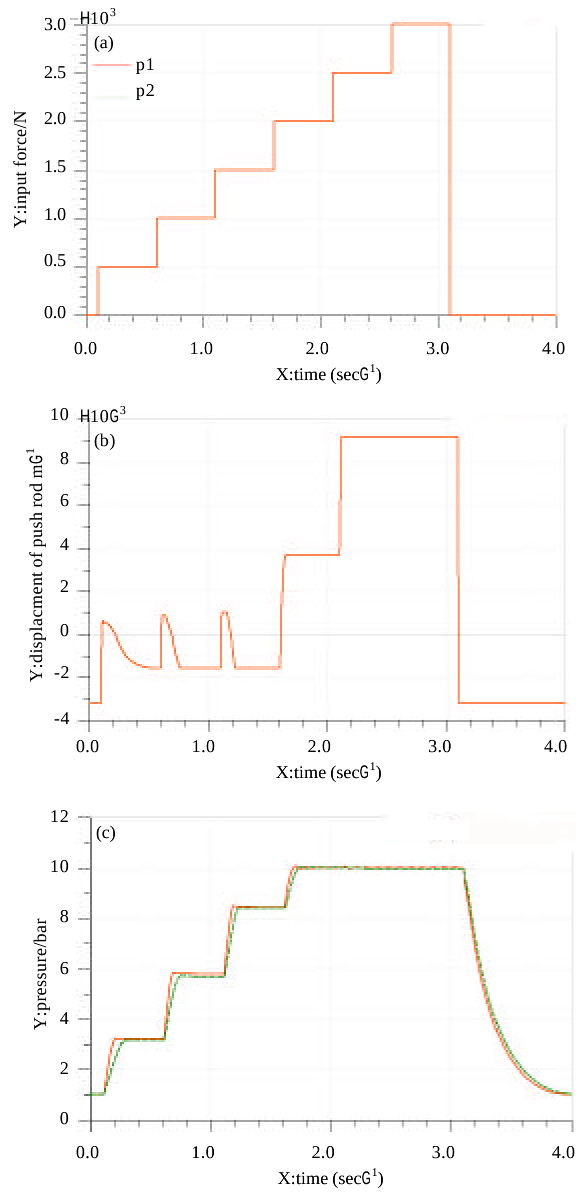

Fig. 8(a-c): (a) In the ladder pressure increasing thrust input, simulation results of (b) the push rod's displacement and (c) the pressure dynamic characteristics

and can't continue to increase. We can see that the pressure of the two circuits reaches 10bar at about 1.75s, which shows that the valve ports can be completely open when the thrust is between 1500 and 2000 N. We also can see that the exhausting starts at 3.1s and the whole exhausting process takes about 0.85s. It almost equals to that of the linear pressure-reducing process.

CONCLUSION

The pneumatic model of the foot valve has been built up through AMESim and the experiments have verified its correctness. By setting the different force input and running the simulation, the corresponding pressure dynamic characteristics have been gotten. This will provide the ideas for development and optimization of such types of foot valves.

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