

Modeling, Experimentation and Sensitivity Analysis of a Pneumatic Brake System in Commercial Vehicles

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ABSTRACT

The main purpose of this research is to investigate the optimal design of pipeline diameter in an air brake system in order to reduce the response time for driving safety using DOE (Design of Experiment) method. To achieve this purpose, this paper presents the development and validation of a computer-aided analytical dynamic model of a pneumatic brake system in commercial vehicles. The brake system includes the subsystems for brake pedal, treadle valve, quick release valve, load sensing proportional valve and brake chamber, and the simulation models for individual components of the brake system are established within the multi-domain physical modeling software- AMESim based on the logic structure. An experimental test bench was set up by connecting each component with the nylon pipelines based on the actual layout of the 4×2 commercial vehicle air brake system. The experimental data of the transient pressure in both secondary and primary brake circuits was measured to verify the simulation accuracy and the positive results of the validation show a potential for investigating the most suitable parameter configuration of the pipeline diameter based on the computer-aided analytical dynamic models. A DOE process is then performed to determine the main factors which could greatly decrease the response time of the brake system. A remarkable improvement can therefore be obtained through altering each pipe diameter according to its direction of trend for the responses it has impact on.

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INTRODUCTION

The brake system is one of the essential parts for ensuring the driving safety [1], and must meet several specific requirements for braking performance and high-speed reaction during rapid braking operation [2]. Compared with hydraulic brake system, the air brake system is more commonly applied in heavy vehicles such as tractor-trailers and agricultural vehicles due to its larger brake force transmitted through air pressure and relatively small sensory feedback when the brake pedal is actuated. As most tractor-trailer vehicles with a gross vehicle weight rating (GVWR) over 19000lb, most single trucks with a CVWR over 31000lb [3], more than 85% of the commercial vehicles in the United States are equipped with air brake system [4], and any incident involving truck brake system would possibly result in environmental and economic repercussions. Therefore the main aim of this paper is to develop and verify the pneumatic dynamic model of air brake system to enhance the brake performance of heavy trucks.

From the view of the basic elements, the air brake system consists of two main subsystems, namely the pneumatic component subsystem and pipeline subsystem. The basic

elements of the pneumatic component subsystem include filters, coupling, valves and brake chambers, and the pipeline subsystem helps to interconnect the pneumatic components into a complex functional engineering system. In recent years, studies have been carried out to develop the pneumatic models of single component. The effect of the pipelines upon the performance of the brake component, however, is always not taken into consideration. Kaminski *et al.* has constructed a computer model of the trailer relay emergency valve within the program MATLAB/Simulink and validated the simulation result by bench test [5]. Ma *et al.* has established the load sensing proportional valve in AMESim environment for robust design of the distribution ratio between front and rear brake force [6]. Natarajan *et al.* developed systems that can control and diagnose air brake systems in order to both sustain and improve their performance [7][8]. As for the design of pipeline layout, Menanteau *et al.* describes a general design tool for pipelines integrated into a CAD environment to avoid resonance and interference condition when the pipe is forced to vibrate [9]. However, the optimal design of the pipeline parameters such as the diameter and length has not been involved.

This paper mainly focused on investigating best design of the pipeline diameter of a 4×2 commercial vehicle brake system in order to reduce the system response time for driving safety. At first, the pneumatic dynamic models of brake valves have been established and packed into super-components in AMESim software environment. Then the super-components are connected by pipeline model to construct an air brake system. To validate the simulation accuracy, a bench test of the brake system was set up and the experimental data of the front and rear pressure has been measured to corroborate the simulation results. In the last section, a corresponded doe analysis is performed to determine the main factors of the pipeline diameters which could greatly decrease the response time of the brake system.

DESCRIPTION OF THE PNEUMATIC SYSTEM

A typical layout of the pneumatic subsystem in the air brake system of a 4×2 commercial vehicle can be shown in Fig.1. The compressed air delivered from the compressor is stored in both front and rear reservoir respectively. When the driver push down the pedal mounted on the treadle valve, the compressed air would be separated into brake chambers through two circuits, the primary circuit and the secondary circuit. The secondary circuit supplies gas to the front brakes, the primary circuit provides compressed air to the rear brakes, and the ratio of the press in these circuits is controlled by load sensing valve connected to the rear axle.

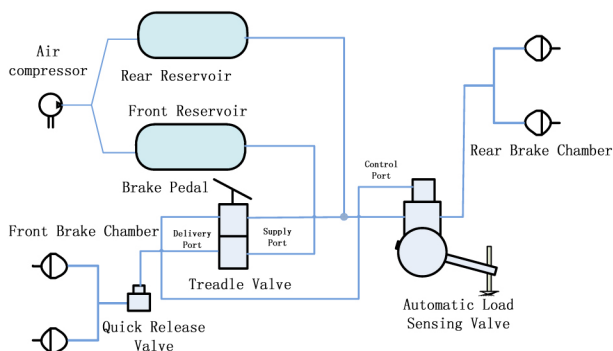


Figure.1. A typical layout of the air brake system in 4×2 commercial vehicle

It can be noted from Figure.1 that the delivery port of the upper chamber in treadle valve is connected directly to the control port of the load sensing proportional valve. This layout helps in quick charging the rear brake chambers when the brake pedal is pushed down by driver. Besides the components and the layout of the brake system, another important factor which would affect the response velocity of the brake system is the length and inner diameter of the pipelines, and a corresponded doe analysis is operated in following chapters.

BRIEF INTRODUCTION AND MODEL OF THE COMPONENTS IN AIR BRAKE SYSTEM

Treadle Valve

The treadle valve is used to regulate the amount of air transported to front and rear brake chambers from storage reservoirs. The schematic of the treadle valve can be shown as Figure.2.

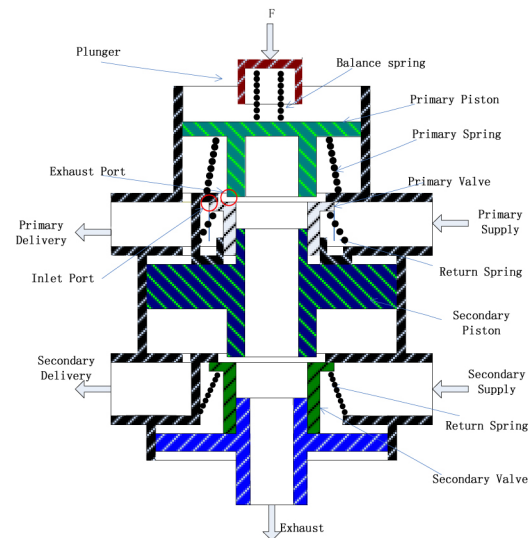


Figure 2. Schematic of the treadle valve

When applying brake, the plunger is actuated by pedal force and moves the primary piston down against the primary spring, closing the exhaust port and opening the inlet port of the primary circuit. The compressed air from supply port flows through the inlet port and then travels to downstream brake components. At the same time, the compressed air would generate a resistance against the movement of the primary piston by acting on its lower side, and in turn gives the driver a so-called 'pedal feel'. As the press at the primary port increases to balance the pedal force and therefore forces the primary piston upwards, the outlet of the primary circuit closes and the exhaust port remains closed as well. The pressure in the primary circuit reaches its maximum value as a result. When the pedal force is released, the equilibrium condition of forces applied on the primary piston is disturbed and the compressed air in primary circuit pushes the piston upwards, which causes the primary piston get off from the primary valve. Then the compressed air can be exhausted to the atmosphere and the brake process could be released. The treadle valve has a symmetry structure and therefore controls the secondary circuit in the same way as the primary circuit. The only difference is that the secondary circuit is actuated by the secondary piston. Figure.3 shows the treadle valve model in AMESim software.

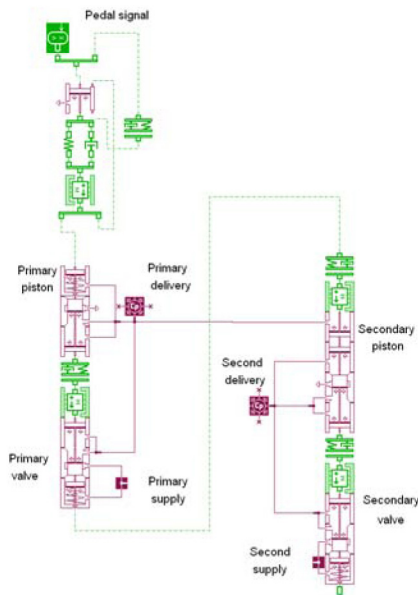


Figure 3. The treadle valve model in AMESim software

Load Sensing Proportional Valve

Load sensing proportional valve can alter the proportion of brake pressure in primary and secondary circuit by adjusting the effective pressure bearing area of the diaphragm according to the load of the commercial vehicle and therefore improve the actual brake force distribution correspondingly. A structure diagram of the load sensing proportional valve can be shown in Figure.4.

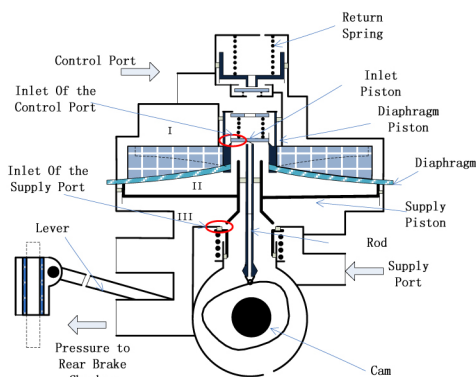


Figure 4. The structure diagram of the load sensing proportional valve

The load sensing proportional valve is mounted on the vehicle chassis and connected to the rear axle by a flexible lever. When the vehicle is empty loaded, the distance between the axle and the valve is the largest and lever stays in the lowest position. As the vehicle is loaded, the distance is reduced and lever moves from its 'empty' position upwards to its 'full laden' position. The movement of lever makes the cam rotate and valve rod is lifted to some position corresponding to the vehicle load. In the process of braking, the pressed air in primary brake circuit flows into the control port, then charges the chamber I and acts on upper side of the diaphragm. The diaphragm would be deflected and forced the diaphragm piston down while the inlet piston remains stable against its return spring after contacting with the rod. The inlet of the control port opens and the pressure in

chamber II increases, and pushes the supply piston down. Then the automatic sensing load valve would behave similar to the treadle valve in the way to open the inlet of the supply port and charge the rear brake chamber. The only difference is that the balance position is changed with the effective area of the diaphragm. When the pressure of air in control port gets low with pedal releasing, the diaphragm returned while the inlet of the supply port is closed and air in the brake chamber can be exhausted to the atmosphere. The AMESim model of the automatic sensing brake can be shown in Figure.5.

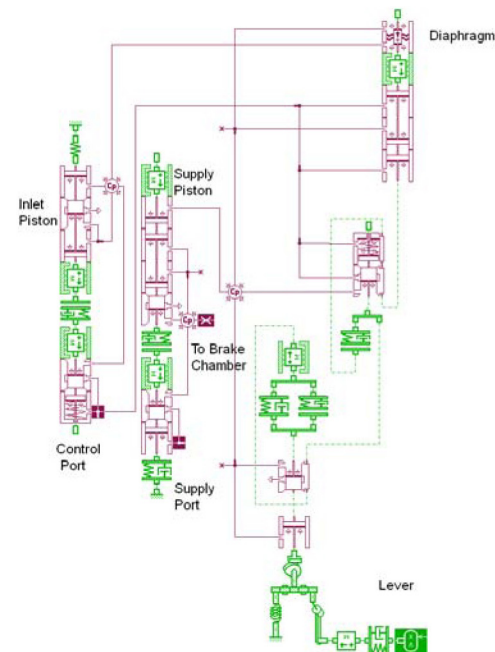


Figure 5. The AMESim model of the load sensing proportional valve

Quick Release Valve

The quick release valve is mounted on front axle of the commercial vehicle and works similar to a 3-port pipe joint when brake is actuated. The compressed air from the secondary circuit would depress the diaphragm and can be separated into front two brake chambers. On the other hand, when the pedal is released, the compressed air in the brake chamber would lift the diaphragm and could be quickly exhausted to the atmosphere as a result. The structure of the quick release valve is shown in Figure 6, and its AMESim model is displayed as Figure 7.

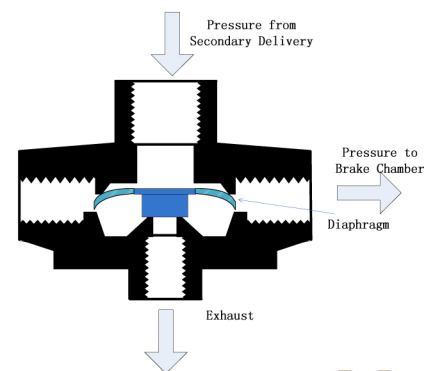


Figure 6. The structure of the quick release valve