PERFORMANCE OF AIR BRAKE COMBINATION VALVE

Saeed Abu Alyazeed Albatlan[1]

UDC: 629.1; 62.783.52

1. INTRODUCTION

The brake system is one of the most important systems in a vehicle for its active safety during operation. A brake system must ensure safe control of a vehicle during its normal operation and must bring the vehicle to a smooth stop within the shortest possible distance under emergency conditions [1, 2]. Air brake systems are widely used in commercial vehicles such as trucks, tractor-trailers, and buses. In these brake systems, compressed air is used as energy transmitting medium to actuate the foundation brakes mounted on the axles [3]. An air brake system for truck and trailer combinations comprises a vehicle load sensing valve to control brake pressure of the vehicle axles [4]. A vehicle load responsive brake control device for adjusting the braking force according to the varying load of the vehicle in each braking range; the purpose of the brake control device is to adjust the braking forces in accordance with the dynamic shifting of the axle loads [5]. A load-controlled fluid pressure regulating valve device for tractor-trailer type vehicle brake systems combines in a single housing a unitary piston valve assemblage capable of performing the functions of a relay valve device and a regulating valve device [6]. Combined vehicle antiskid and load-dependent brake control system in digital control of the individual wheel brake pressure regulating valves is provided. These regulating valves may be operated individually or on a per axle basis to vary the brake pressure independent of the operator-controlled brake valve device [7]. For vehicles without electronic control of brake pressure, there is need to vary the control pressure for different load conditions. This is done in order to avoid the instability that would occur if wheels lock (start skidding) in an unsuitable order. This device is called a load sensing valve [8]. In [9] new generations of mechanical and pneumatic load sensing valves are developed with an integrated relay valve and connection to ABS to meet the requirements for modern commercial vehicles. A model is proposed for predicting the pressure transients in the brake chamber of a brake system delivered by a treadle valve [10]. A control scheme for regulating the pressure in the brake chamber is presented [11]. The details of a mathematical model for an air brake system in the presence of leaks can be found in [12]. The complete mathematical models of a relay valve for commercial vehicles are shown in [13].

The aim of the present paper is to evaluate the performance characteristics of the combination valve (Load sensing relay valve). A test rig is built-up and a mathematical modeling and simulation using MATLAB® are used. The model validation is proved by comparing the test results with the simulation results.

[1] Saeed Abu Alyazeed Albatlan, Higher Technological Institute, 10th of Ramadan City, 6th October Branch Cairo, Egypt, Email: saeedzeed@yahoo.com

2. THEORETICAL ANALYSIS

It is important to understand the construction and operation of the combination valve to formulate its mathematical model and to establish the computer simulation program for its operation.

2. 1 CONSTRUCTION AND OPERATION OF THE COMBINATION VALVE

Figure 1 shows the various parts of a combination valve. The parts are assembled in the following way as shown in Fig. 2. The operation of brakes takes place when the driver can apply, hold, or release it. Each of these operations is explained in the following phases:

Apply phase, when the brake pedal is pressed, the treadle valve allows the permissible air to flow to combination valve through the input port I. This acts on the primary piston 1, as shown in Fig. 2. This causes the primary piston to move and come into contact with cam rod 2. At this point port of cam rod is closed. During this phase the combined movements of combination lever and cam positions open the valve 3 and the port of cam rod remaining closed. This causes the air moves to charge chamber 6. This closes atmospheric port 4, of valve 5.

Second phase: the pressure in chamber 6, increases to a level where it balances the primary piston force, the inlet valve 3 is closed. During this phase the valve 19 is open. This causes compressed air from the storage reservoir 7, to flow into chamber 17, and wheel brake chamber through 8. This phase is called the hold phase. The pressure of air in the brake chamber reaches a steady value.

Third phase: when the pedal is released the applied force on the primary piston is reduced. This causes air in the chamber 6 to get out as exhaust through cam rod port, at this point valve 3 opens and air from the brake chamber flows to the atmosphere. This phase is called the released phase. This valve is used in tractor on rear axle to adjust the braking forces in accordance with the dynamic shifting of the axle loads.

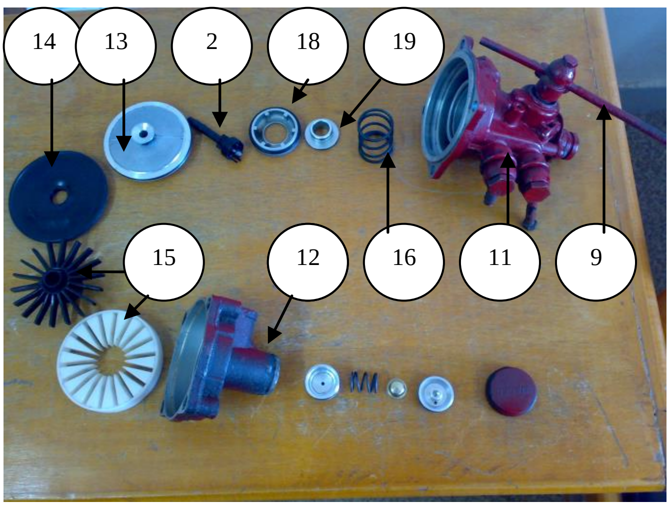


Figure 1 Various parts of combination valve

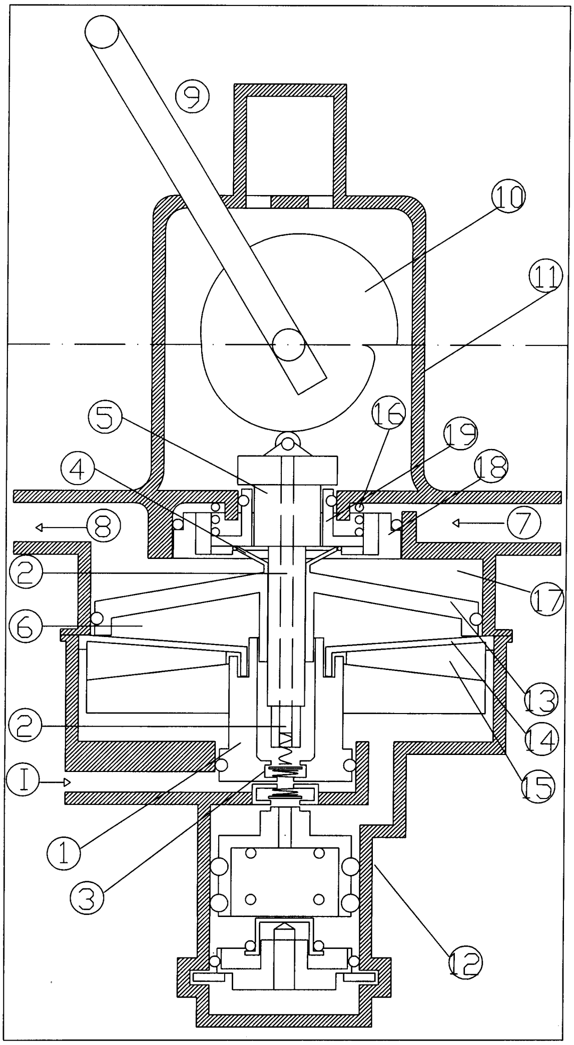


Figure 2: Combination valve construction

I - Inlet valve port to chamber (A) from treadle valve, 1 - Primary piston, 2 - Cam rod with atmospheric port, 3 - Inlet valve from treadle valve, 4 - Atmospheric control valve, 5 - Regulating rod, 6- Camber (B), 7 - Inlet valve port from reservoir, 8 - Outlet to wheel brake chamber, 9 - Loadsensing lever 10-Load sensing Cam, 11- Upper valve body, 12- Lower valve body, 13-Relay piston, 14- Variable area diaphragm, 15- Variable area Diaphragm disc, 16- Coil spring, 17- Chamber (C), 18- Inlet valve seat, 19- Inlet valve from reservoir

2. 2 MATHEMATICAL MODEL

The combination valve mathematical model can be represented in two stages according to air charged in each chamber.

Stage (1)

During apply and hold phases, when the pressure in chamber 6 increases to a level where it balances the primary piston force and the inlet valve 3 is closed.

$$A_A \times P_P = P_B(A_A + A_V)\,, \tag{1}$$

$$P_B = P_P \times \frac{A_A}{(A_A + A_V)}\,, \tag{2}$$

$$A_V = \frac{A_A(P_P - P_B)}{P_B}\,, \tag{3}$$

Where are:

- P_B = pressure in chamber 6, bar
- P_P = treadle valve pressure, bar
- A_A = chamber (A) surface area =784.37* 10^{-6} m^2
- A_V = variable area, m^2

Stage (2)

During hold phase, when compressed air from the storage reservoir flows into chamber 17, and brake chamber.

$$P_B \times A_P - F_S = P_C \times A_P\,, \tag{4}$$

$$P_C = P_B - \frac{F_S}{A_P}\,, \tag{5}$$

Where:

F_S = spring force = 203 N

P_C = pressure in chamber 17 = wheel brake chamber pressure, bar

A_P = primary piston surface area, m^2

Mathematical model of the combination valve constructed on Matlab (Simulink) is shown in Fig. 3. This Figure represents the behavior of valve during operation as follow: Equation (1) is having P_p input and the output is P_B and A_V, where as the input A_A is constant. Equation (2) P_B and P_P represent the input, but A_V represents the output. The output of equation 2 A_V is used to feed the input equation 1 so that the outcome would P_B, The second stage P_B and $\frac{F_S}{A_P}$ are the input and the P_C is the output as shown in equations 4 and 5.

3. EXPERIMENTAL WORK

The objective of the experimental work is to test the combination valve under different static load conditions, and to measure the behavior of line pressure brake axels. The experimental data were used for validating the mathematical model results and to evaluate their performance characteristics.

Figure 4 shows a general layout of the test rig, which can be divided, into three main groups: test rig description, the measuring instruments and data acquisition components [DAQ]. The details of each group are given below.

3. 1 TEST RIG DESCRIPTION

The test rig is constructed to simulate the vehicle air brake system. The rig uses actual air brake system units and components. It allows testing different types of pressure regulator valves.

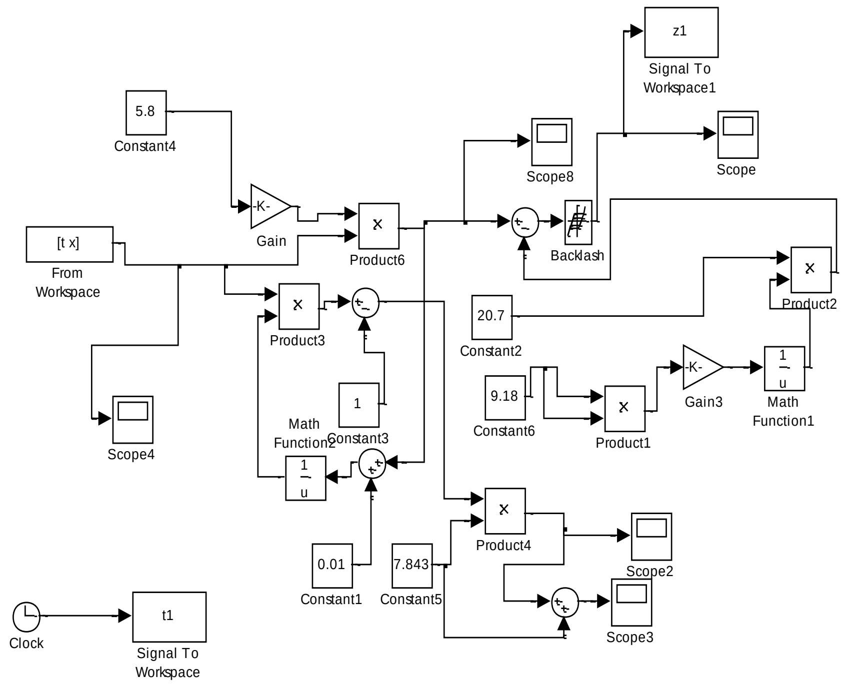
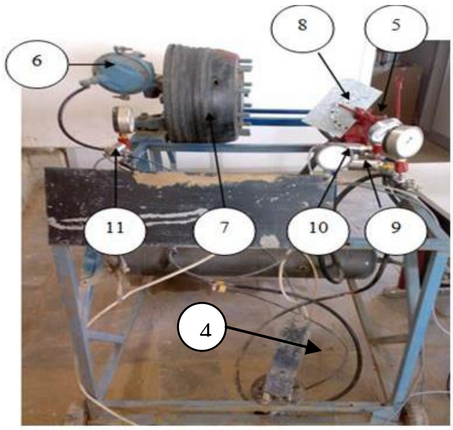


Figure 3 Valve block diagram (Simulink)

The air brake system includes an air compressor 1, coupled with electric motor 2, an air tank 3, brake foot valve (treadle valve) 4, combination valve 5, rear brake chamber 6, rear axle wheel and hoses 7, to connect different components , as shown in Fig. 4 (a,b,c). Air compressor actuating mechanism showed in Fig. 4 consists of electric motor and V- belt connecting air compressor with motor pulley. To have a wide range of rear axle load, the load sensing lever indexing plate 8, is provide with holes which are corresponding to different loads on the rear axle.

a. Data Acquisition system



b. Air brake system components

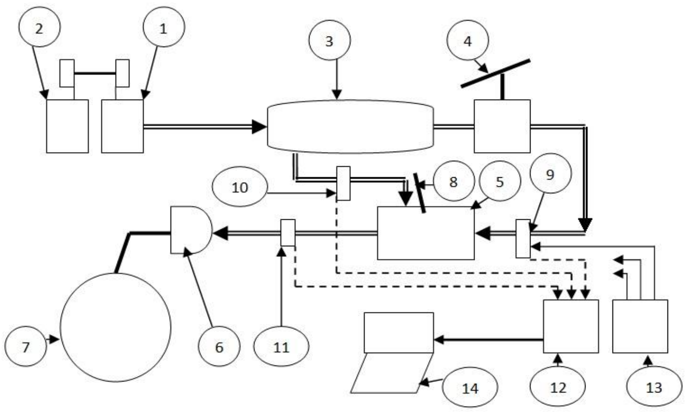


Figure 4 Test rig components and layout

1- Air compressor, 2- Electric motor, 3- Air tank , 4- Brake foot valve (treadle valve), 5- Combination valve, 6- Rear brake chamber, 7- Rear axle wheel, 8- Load sensing lever with index plate, 9, 10, 11 – Pressure transducers, 12- Data acquisition board [(A/D) converter], 13- DC supply, 14- CPU

3. 2 THE MEASURING INSTRUMENTS

Test rig is equipped with several measuring instruments, which are necessary for performing the tests. The measuring instruments are shown in Fig. 4, which include:

PRESSURE TRANSDUCERS:

A pressure transducer is mounted at the entrance of each of the combination valve 9, from brake foot valve (treadle valve), entrance to relay valve 10, from the air tank, and output of the relay valve 11, by means of a custom designed and fabricated pitot tube fixture. The purpose of this measurement is to validate the mathematical model results and evaluate their performance characteristics.

3. 3 DATA ACQUISITION COMPONENTS [DAQ]

All the transducers are interfaced with a connector block through shielded cables. The connector block is connected to a DAQ board [14], (connect with computer by USB cable) that collects the data during experimental test runs. This DAQ board can measure (16-channel single ended inputs or 8 channel differential inputs) and can provide two analog output signals. The DAQ board discretizes the analog input signals using an analog-to-digital (A/D) converter 12, and the resulting digital signals are stored in the computer. An application program written in MATLAB / Simulink is used to collect and store the data in the computer [15]. DC supply 13, is used to provide pressure sensors with the required electrical volts. All the transducers are interfaced to a dell-500 computer 14, through an amplifier and signal conditions devices.

4. RESULTS AND DISCUSSION

In this section it is shown clearly that the experiments corroborate the model. Experiments were conducted at different supply pressures for different brake pedal inputs and different cases covering the whole range of load conditions of the vehicle to evaluate the performance of the combination valve.

4. 4 MODEL VALIDATION

The model is validated by comparing experimental results obtained from the test rig undergoing different load conditions with model simulation results. Figures 5 to7 show the reservoir pressure, treadle valve pressure (relay pressure) and chamber brake line pressure, plotted against the brake time, for experimental and simulation results in different cases covering the whole loading conditions range of the vehicle.

Implementation and tests on a test rig validate the combination valve mathematical model.

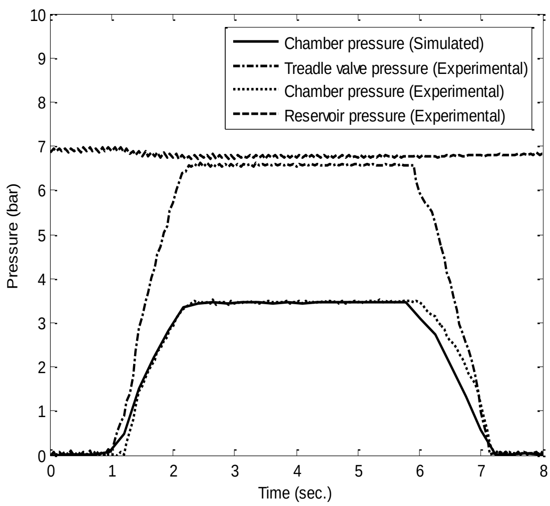


Figure 5: Simulated and experimental air brake pressure at no-load

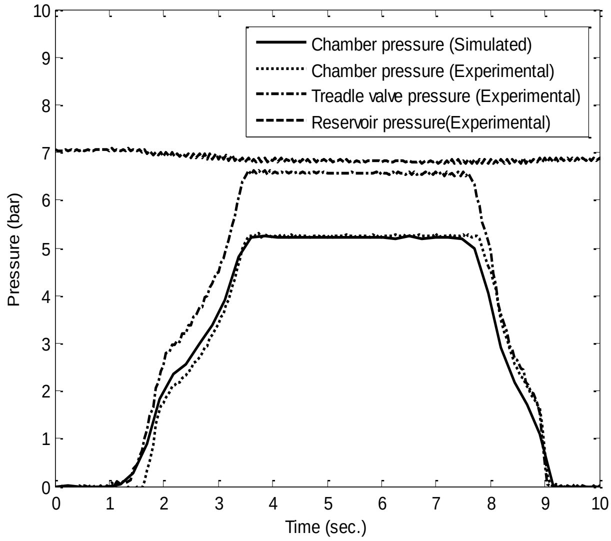


Figure 6 Simulated and experimental air brake pressure at half-load

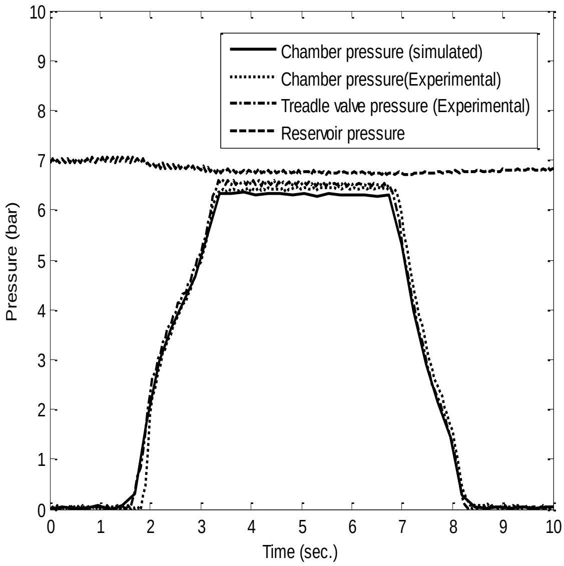


Figure 7 Simulated and experimental air brake pressure at full-load

4. 5 EVALUATING THE PERFORMANCE CHARACTERISTICS OF THE VALVE

Figure 5 represents the behavior of treadle valve pressure, and brake chamber line pressure at no-load, where three phases can be noticed as follows:

Phase (1):

During this phase the brake line pressure increases up to the required pressure whose valve depends on the loading condition of the vehicle. This phase is called the apply phase. It depends on pedal travel rate and required braking force.

Phase (2):

The brake line pressure during this phase is constant. This phase is called the hold phase affected by reservoir pressure, relay valve parameters and required braking force.

Phase (3):

This phase is called the released phase, affected by pedal release rate. From Figures 5 to7 it can be noted that:

The combination valve automatically controls the pressure in brake actuators depending on vehicle load. The distribution of the brake pressure between axle wheels has a large effect on braking performance and vehicle dynamic behavior during braking. Improvement in handling, vehicle stability, stopping distance, and braking efficiency occur due to improved brake balance [16, 17].

4. 6 THE INFLUENCE OF OPERATING PARAMETERS ON VALVE PERFORMANCE

The behavior of combination valve is affected by many factors; among them are the operating parameters. The variation of brake chamber line pressure presented in Figures 8 to 10 is due to load level, and the treadle valve pressure related to pedal rate, show that the treadle valve pressure starts to increase during braking applied. The values of this pressure are affected by the load and pedal rate. This is shown in Figures 5 and 8 respectively.

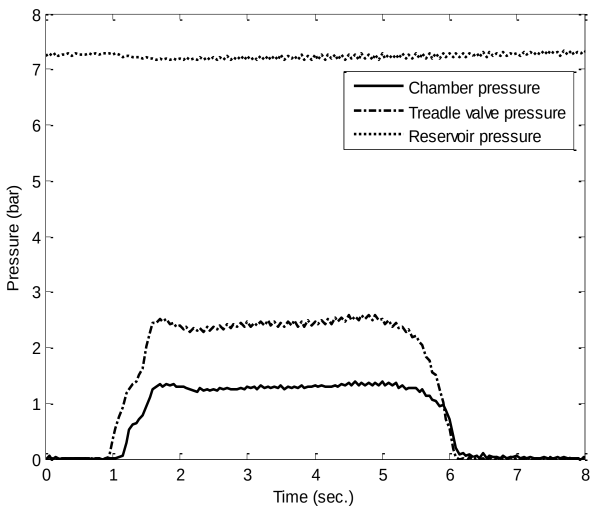


Fig. 8: *Experimental result at no-load - part pedal travel*

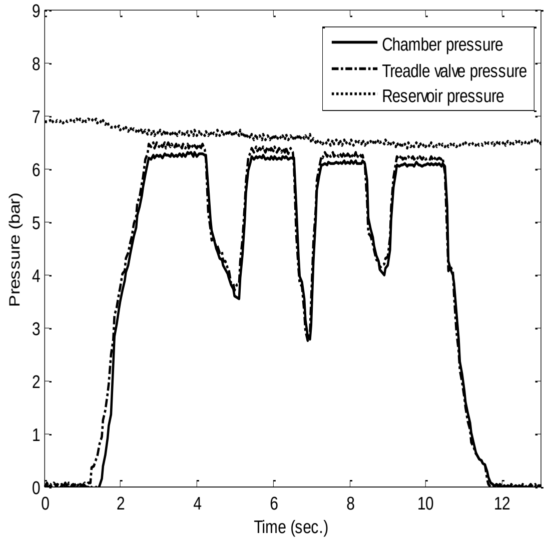


Fig. 9: *Experimental result at full- load -variable pedal travel*

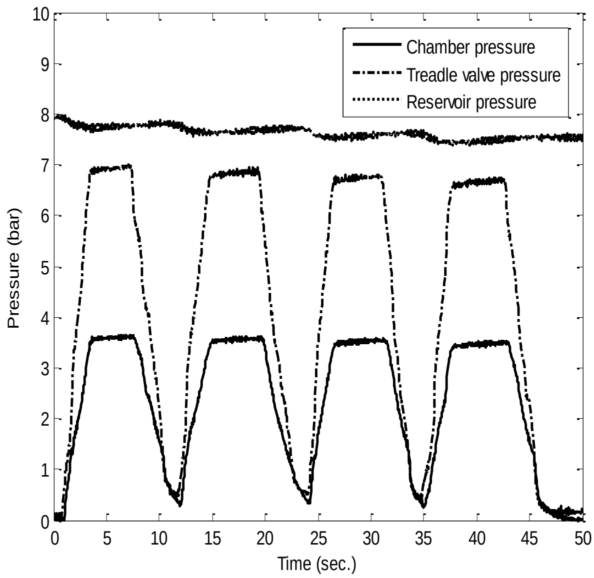


Fig. 10: *Experimental result at no-load and fluctuate pedal travel*

From figures, 8 to 10 it can be noted that:

- There is a high response for the brake chamber pressure with respect to the treadle valve pressure.

- The brake chamber pressure changes in proportion to loading conditions and treadle valve pressure.
- The treadle valve pressure is regulating valve device for combination valve operation.

5. CONCLUSIONS

- Mathematical models and a computer simulation program is used to evaluate the valve
- The measurements performed on the valve using the test rig concord with mathematical model.

6. REFERENCES

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