INVESTIGATION OF PARAMETERS AFFECTING HYDRAULIC BRAKE LOAD SENSING VALVE PERFORMANCE

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1. INTRODUCTION

The vehicle brake system requires performing safety under a variety of operation conditions and when the vehicle is partially or fully loaded, when braking is applied either in a straight forward or in a cornering condition. Load sensing brake proportioning valve (L.S.P.V) is a mean of proportioning the ratio of front - to - rear wheel retarding (braking) forces at the full range of vehicle loading and deceleration. It is well known that to achieve maximum deceleration or “ideal braking” the front and rear wheels should approach the locking point simultaneously. As the wheel load changes as a result of weight transfer, hence different braking force will be required to achieve the ideal braking [1-5]. Albatlan [6] presented complete models for the pressure limiting proportioning valve, link-less brake deceleration sensing valve and load-sensing proportioning valve. El Gindy et al [7] developed a mathematical model that describes the performance of a commonly used load – sensing brake proportioning valve. Khan et al [8], presented models of an analytic dynamics for vehicle brake apply system with proportioning valve. Also H. Lwai et al [9], described a link less brake deceleration sensing proportioning valve designed and developed for passenger cars and light trucks. In the brake system, it is important to reduce the rear brake pressure in order to secure the safety of the vehicle in braking. By using a L.S.P.V and electronic Load sensing brake proportioning valve (E.L.S.P.V), the L.S.P.V is a mechanical system and its brake efficiency is lower than the efficiency of E.L.S.P.V. But the cost of E.L.S.P.V is too higher so its application to the vehicle is not economical [10]. Fitting one load sensing valve for each wheel at rear and front axle improves in brake efficiency for the vehicle in its straight motion and in its cornering motion, depends on the variation of load distribution, road curvature and moving speed [11, 12]. Selecting the correct adjustable load-sensing proportioning valve for any vehicle entails not only selecting the proper point at slope limiting begins (the knee point), but also selecting the proper rate at which rear brake line pressure builds point (the slope) [13].

The aim of the present paper is to provide measures for changing valve performance according to changing its main components data and characteristics. This helps designers and users of a load sensing proportioning valve as a guide for selecting its component parameters according to their needs. Therefore; mathematical models as well as the simulation model in addition to measurements are carried out for the valve and characteristic changes are presented.

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2. ACRONYMS AND NOMENCLATURE:

- D Plunger diameter (mm)
- A_D Plunger surface area (mm2))
- D_1 Rubber ring outer diameter (mm)
- A_{D1} Rubber ring surface area (mm2))
- d Plunger stem diameter (mm)
- A_d Plunger stem surface area (mm^2)
- X_O Clearance between plunger and rubber ring (mm)
- Z Rubber ring deflection (mm)
- K_s Spring stiffness (N/mm)
- K_r Stiffness of the rubber ring (N/mm)
- F_{xs} Spring force (N)
- F Plunger force (N)
- P_f Front line pressure (bar)
- P_k Knee point pressure (bar)
- P_r Rear line pressure (bar)

3. THEORETICAL ANALYSIS

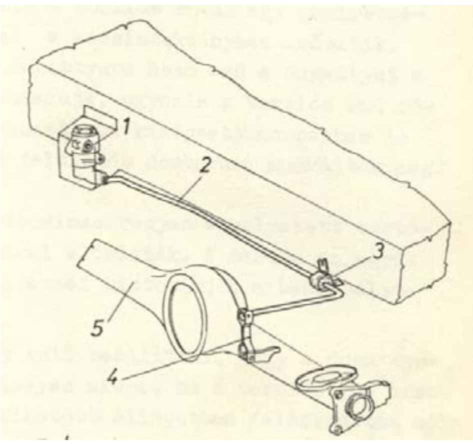
Theoretical Simulation based on the proposed mathematical models of the load-sensing proportioning valve requires that its function be represented by suitable mathematical terms. To do this, it is necessary to analyze the operation of the proportioning valve and actuating mechanism.

3. 1 DESCRIPTION OF THE LOAD-SENSING PROPORTIONING VALVE (L.S.P.V).

The load-sensing proportioning valve is mounted on the rear part of the vehicle body and connected to the axle by a valve lever (torsion bar), as shown in Fig. 1. Fig. 2 shows the construction of the valve. The input line pressure P_f is equal to the line pressure of the front axle. The output line pressure P_r is a controlled pressure which is the line pressure of the rear axle. As the rear load increases the deflection increases and the twist angle of the torsion bar increases which causes an increase in the force, F acting on the end of the plunger so affecting the rear line pressure. Details of the dimensions and specifications of the valve components are shown Table 1.

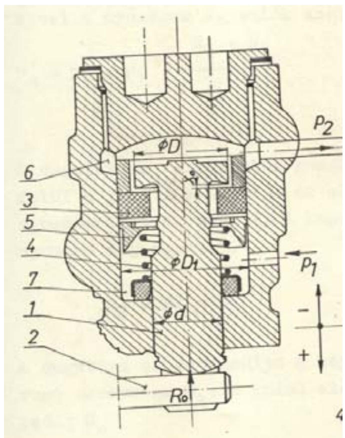
Table 1 *Valve parameter values [7]*

Parameter	Description	Value
D	Plunger diameter	19.0 mm
A_D	Plunger surface area	285.0 mm
D_1	Rubber ring outer diameter	25.4 mm
A_{D1}	Rubber ring surface area	507.0 mm^2
d	Plunger stem diameter	14.0 mm
A_d	Plunger stem surface area	154 mm^2
X_O	Clearance between plunger and rubber ring	0.5 mm
K_s	Spring stiffness	10.0 N/mm
K_r	Stiffness of the rubber ring	5000.0 N/mm
F_0	Force due to spring assembling	49.05 N



1. Load sensing proportioning valve
2. Torsion bar
3. Attached to chassis
4. Attached to rear axle
5. Rear axle

Fig. 1 *Load sensing proportioning valve installation*



1. Plunger
2. Torsion bar
3. Rubber ring
4. Coil spring
5. Coil spring cap
6. Valve housing

Fig. 2 *Load sensing proportioning valve construction. [7]*

3. 2 MATHEMATICAL MODEL

The load-sensing proportioning valve operation can be presented in two stages according to the valve plunger movement.

2.2.1 Stage (1)

The plunger should start to move downwards by a distance (X_0), at this position the plunger is in contact with rubber ring.

$$P_k = \frac{F + F_s}{A_d} \tag{1}$$

Where:

$$P_k = P_f = P_r \tag{2}$$

2.2.2 Stage (2)

Due to the continuous increase in P_f, the rubber ring is forced to be imbedded in the plunger which moves with it in the up - word direction by distance, Z , in this stage the increase of rear pressure can be determined according to:

$$P_r A_{D1} = P_f (A_{D1} - A_d) + F + Fs - Z(Kr + Ks) \tag{3}$$

$$P_r = \frac{P_f (A_{D1} - A_d) + F + Fs - Z(K_r + K_s)}{A_{D1}} \tag{4}$$

$$Z = \frac{P_f (A_{D1} - A_d) + F + F_s - P_r}{K_r + K_s} \tag{5}$$

Where:

$$F_s = X_0 K_s \tag{6}$$

Mathematical Model of the load-sensing proportioning valve constructed on Matlab (Simulink) as shown in Fig. 3. Valve data is presented in Table 1, used as inputs to the model simulation.

4. EXPERIMENTAL WORK

The objective of the experimental work is to test the load sensing proportioning valve (LSPV) under different load conditions, and to measure brake line pressure in front and rear axels. The experimental data were used for validating the mathematical model results.

The test rig was designed and constructed to simulate the vehicle hydraulic brake system. The brake apply system was set up on a test rig according to the plate shown in Fig. 4. The components to be tested include a brake pedal, tandem master cylinder, two hydraulic brakes lines connected to front calliper and rear drum with load sensing proportioning valve. The test is carried out in static manner, i.e. no dynamic loads occur. This test rig is equipped with devices in order to measure the master cylinder outlet pressure, the line pressure delivered to front (P_f) and rear wheels (P_r) by using hydraulic pressure transducers and the pedal travel (D_2), valve plunger displacement (D_1) using position sensors. All the transducers are interfaced to a dell-500 computer, through an amplifier and signal conditions devices. The dell-500 computer is used for data acquisition and data storage. Details about this test rig a given in [6].

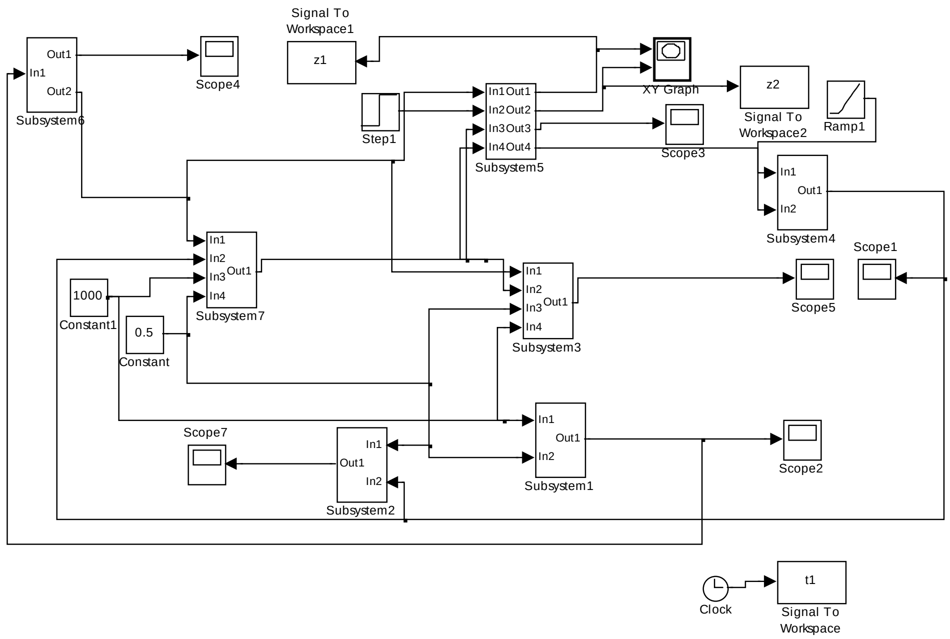
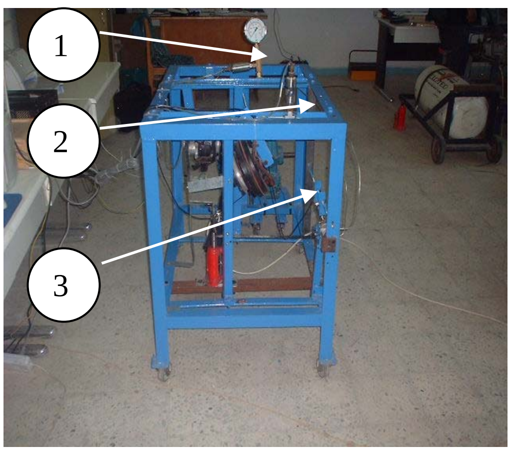


Fig.3 *Valve block diagram -Simulink*



1. Front pressure sensor, 2. Rear pressure sensor, 3. Load sensing proportioning valve

Fig. 3 *Test rig*

5. RESULTS AND DISCUSSION

This section presents validation of model simulation results**.** It also contains a study of the influence of valve parameters on its Performance behaviour.

5. 3 MODEL VALIDATION

In order to validate this model, experimental results are compared with model simulation ones. Figs. 5 to 7 show the rear brake line pressure plotted against the front line pressure, for experimental and simulation results in different cases covering the whole loading conditions range of the vehicle.

The results show a good agreement between simulation and experimental results.

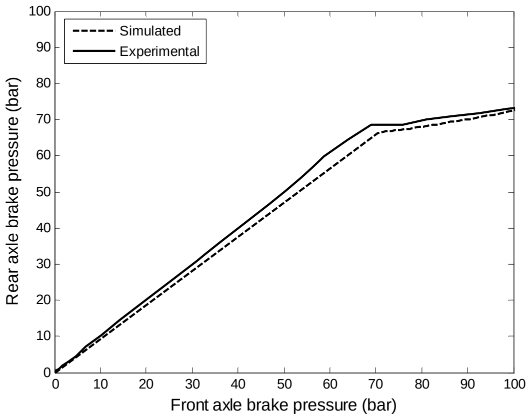


Fig. 5 *Simulated and experimental for front and rear axle brake pressure*

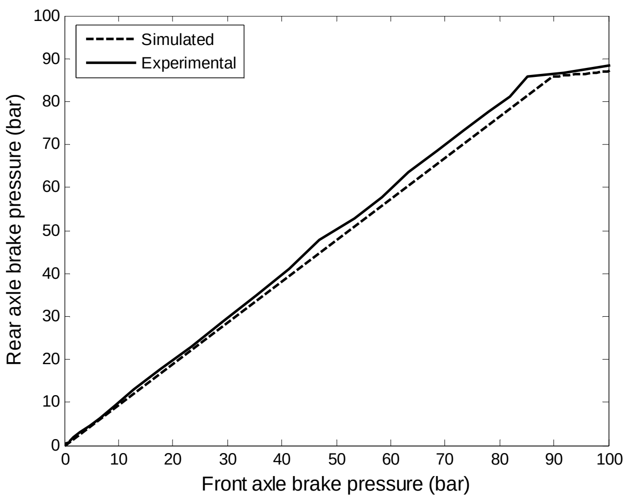


Fig. 6 *Simulated and experimental for front and rear axle brake pressure*

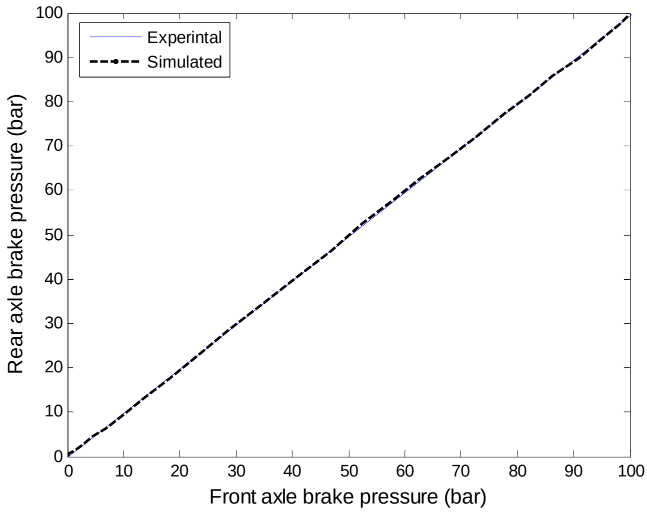


Fig. 7 *Simulated and experimental for front and rear axle brake pressure*

5. 4 THE INFLUENCE OF VALVE PARAMETERS ON ITS PERFORMANCE

Performance behaviour of L.S.P.V is affected by many factors, among them, the rubber ring stiffness, coil spring stiffness, clearance between plunger and rubber ring, plunger area ratio and plunger force.

The Results shown in Figs. from 8 to 14 represent the relation ship between the rear brake line pressures against the front line pressure, and indicate performance behaviour of the valve under effect of each parameter.

4. 2. 1. Effect of the rubber ring stiffness

Figure 8 compares directly between the performance behaviour of the valve at different rubber ring stiffness, 180%, 140%, 100%, 60% and 20%. The figure curves have the same knee point, but with different slopes, at lower values of rubber ring stiffness the slopes vary greater, due to increase rubber ring deflection.

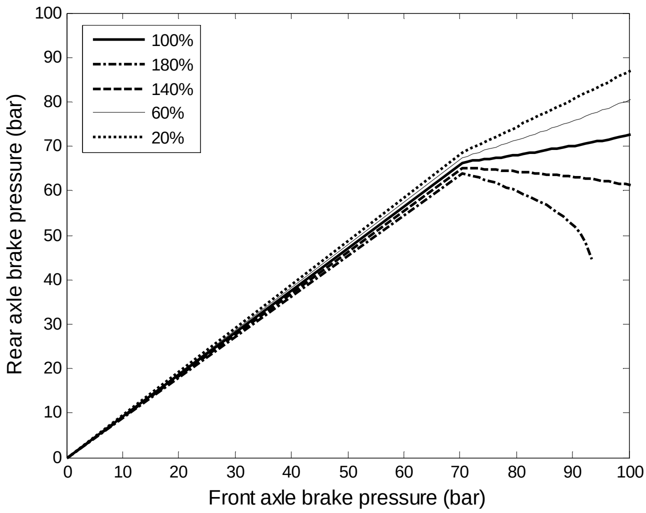


Fig. 8 *Effect of rubber ring stiffness*

4. 2. 2. Effect of the coil spring stiffness

Figure 9 represents the performance of valve at different ratio, 200%, 175%, 100%, 50% and 25% of coil spring stiffness. As indicated in this figure, all curves are identical; i. e. the same knee point and slopes. The effect of coil spring stiffness can be neglected.

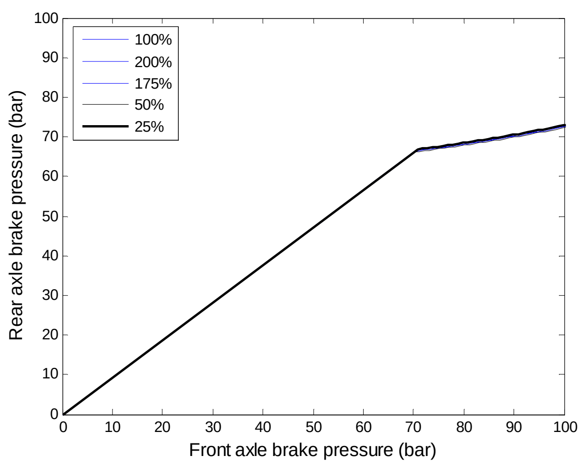


Fig. 9 *Effect of coil spring stiffness*

4.2.3. Effect of the clearance between plunger and rubber ring (X_0)

Figure 10 represents the performance of valve at different ratio, 250%, 200%, 150%, 100% and 50% of clearance between plunger and rubber ring**.** As indicated in this figure, all curves are identical; i. e. the same knee point and slopes. The effect of clearance between plunger and rubber ring can be neglected.

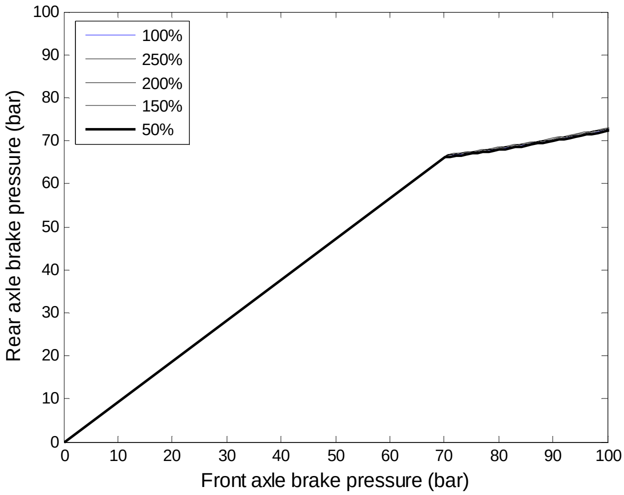


Fig. 10 *Effect of clearance between plunger and rubber ring*

4. 2. 4. Effect of the plunger area ratio

Figures 11 to 13 compare directly between behavior performances of the valve at different cases of area ratio.

4.2.4.1 Case (I):

Figure 11 shows values of the knee-point pressure are changed according to plunger stem surface area. The value of knee-point pressure increases clearly with lower plunger stem surface area.

4.2.4.2 Case (II):

Figure 12 shows values of the knee-point pressure increases when plunger stem surface area decreases and consequently plunger surface area increases.

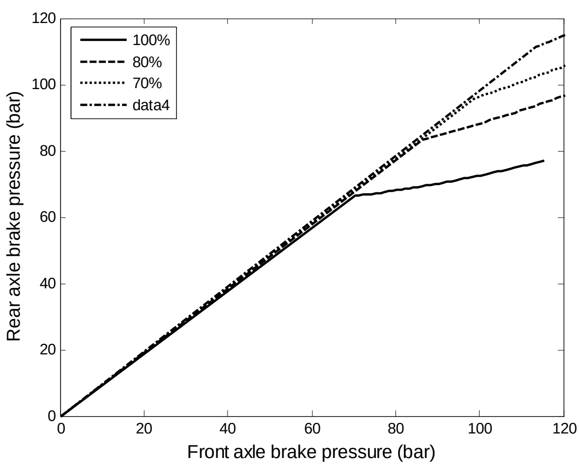


Fig. 11 *Effect of plunger area ratio – Case (I)*

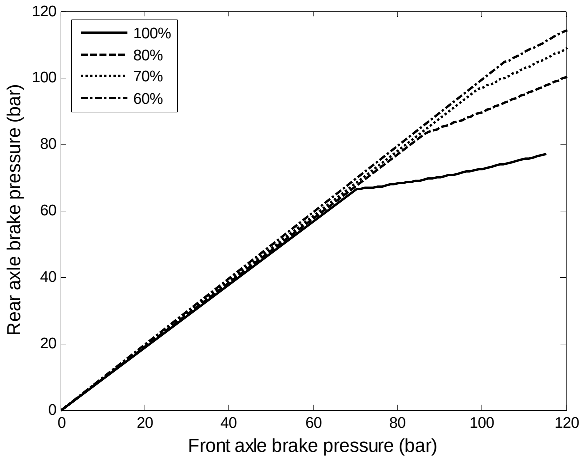


Fig. 12 *Effect of plunger area ratio – Case (II)*

4.2.4.3 Case (III):

Figure 13 shows values of the knee-point pressure are decreased when plunger stem surface area and plunger surface area increase.

As shown from Figs. 11 to 13, the knee point pressure changes according to area ratio and same trend of slope.

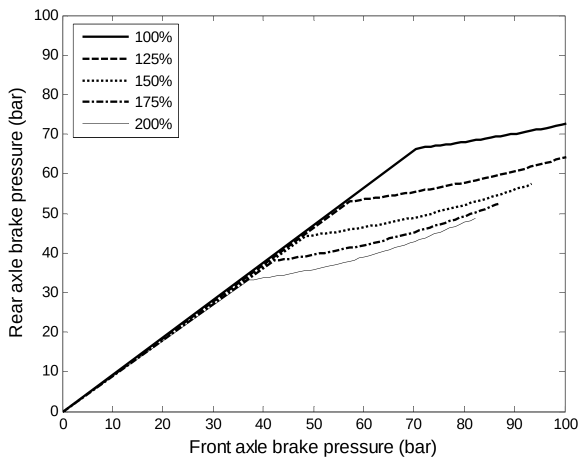


Fig. 13 *Effect of plunger area ratio – Case (III)*

5. 5 EFFECT OF THE PLUNGER FORCE.

Figure 14 represents the complete performance behavior at different values, 250%, 200%, 150%, 100% and 50% of plunger force. As shown from Fig. 14, the knee point pressure moves towards the higher ratio and same trend of slope.

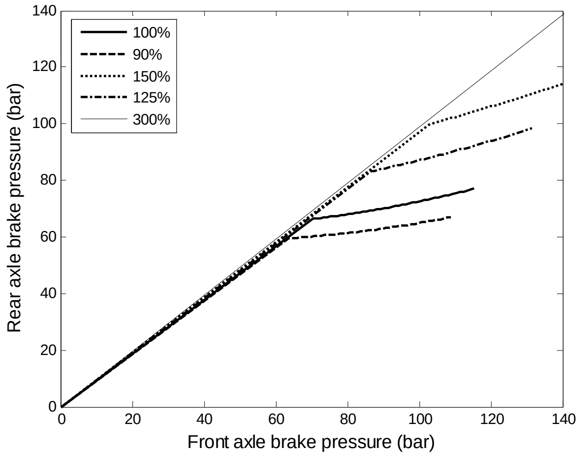


Fig. 14 *Effect of plunger force*

6. CONCLUSIONS

The measurements performed on the valve using a simple test rig show a good agreement with the mathematical model. Performance behaviour of load-sensing proportioning valve is affected by internal design parameters, the knee point affected by plunger area ratio and plunger force. Monover, the slope affected by rubber ring stiffness. The effective of coil spring stiffness and clearance between plunger and rubber ring can be neglected. Selecting the correct adjustable load-sensing proportioning valve for any vehicle entails not only selecting the proper point at slope limiting begins (the knee point), but also selecting the proper rate at which rear brake line pressure builds point (the slope).

7. REFERENCES:

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